A SIMPLE METHOD FOR INFLUENCING AMPLITUDE AND ACCELERATION OF SHAKEN FRUIT TREES

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Abstract

To achieve similar amplitudes and accelerations for larger orchard trees than for smaller ones with unchanged shaker machine setup, a slider crank type shaker with an extra unbalanced mass was suggested. This mass was able to slide free in direction of shaking with defined stroke. The kinematic model of the new shaker arrangement was set up and orchard tests were carried out with an experimental rig to prove the effect of the extra mass. As a result of the model calculation the extra mass resulted in higher amplitudes for larger tree masses and didn't change them below a certain mass value. In orchard tests a smaller and a larger tree was involved. Both were shaken with the experimental rig in 4 different setups. As a result of the tests the best setup seemed to be when the stroke was set to 15 mm. In this case the rig had no effect on the smaller tree and increased the acceleration and amplitude of the larger one by about 50 ms^{-2}.

Keywords

fruit tree shaker, harvesting, shaker frequency and amplitude

Introductions

In the shaker harvesting practice the amplitude of fruit bearing branches and the frequency of shaking play the most important role in fruit detachment, as Fridley and Adrian, 1966 have reported. According them, the detachment in % is:

$$L = 100 \cdot \left(1 - e^{-cS^a \omega^b}\right)$$

where S is the stroke of the branch (mm)

ω is the angular frequency of shaking (1/s)

a, b and c are empiric constants, related to the fruit variety

To avoid tree damages both stroke and angular frequency has its upper limit in the practice.

Replacing the fruit tree by a three-element model and vibrating it virtually sinusoidal, its amplitude can be calculated as follows (Fig. 1):

$$X_M = \frac{mr\omega^2}{\sqrt{\left(k - M_t\omega^2\right)^2 + \left(c\omega\right)^2}} \qquad 1$$

Where

- X_M is the trunk amplitude of the model tree trunk in m;
- m is the unbalanced mass of the shaker in kg;
- M is the mass of the tree and of those shaker parts, which are joint to the trunk in kg;
- M_t is the total mass (m+M) of the limb-shaker system in kg;
- c is the viscous damping coefficient of the limb in Nsm^{-1};
- k is the spring stiffness in Nm^{-1};
- r is the eccentricity of the unbalanced mass in m;
- ω is the shaking frequency in rad s^{-1};

For the amplitude of the unbalanced mass m the following equation stands:

$$X_m = \sqrt{X_M^2 + r^2 - 2X_M r \cos\phi} \qquad 2$$

were:

$$\phi = arctg \frac{kc\omega}{1 - M_t k_1 \omega^2} \qquad 3$$

Acceleration of the shaken tree can be calculated easily as follows:

$$a = X_M \omega^2 \qquad 4$$

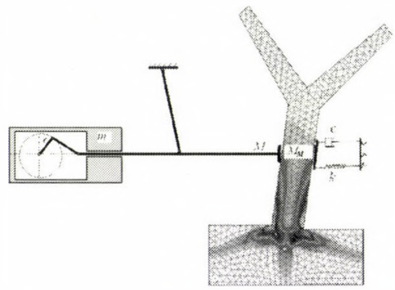

Figure 1. The three-element fruit tree model with the inertia shaker

In the case of unchanged shaker machine setup, for larger trees the shaker input to the trunk results in smaller amplitude than for younger trees with smaller trunk diameter. Possibilities to reduce losses due to reduced amplitude at larger trees are limited. To achieve an appropriate stroke for larger trees as well, the unbalanced mass of the inertia shaker must be increased.

The effect of unbalanced mass m on trunk amplitude can be studied on Figure 2. (Láng, 2008). I. e. increasing the unbalanced mass from 130 to 160 kg, the amplitude of the trunk will increase in the whole examined frequency spectrum of 0-16 Hz. Due to the increased mass, the power demand of the shaker increases as well.

The unbalanced mass can be changed on some shaker machines however only in out of work position, which takes valuable time in the harvesting process.

The aim of the investigation described below was to find a simple solution for a partly automatic adjustment of unbalanced mass to the trunk stroke.

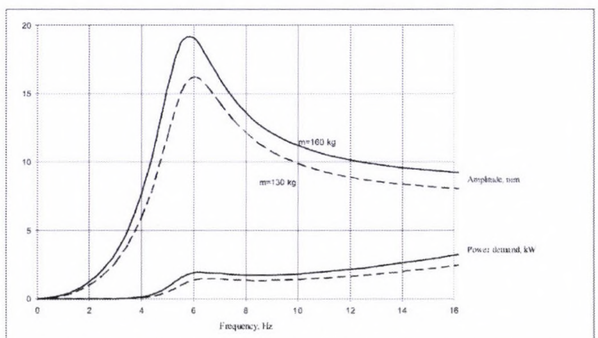

Figure 2. The effect of the change of the shaker's unbalanced mass

Material and methods

The kinematic model

Figure 3 shows the effect of changing trunk mass on the amplitudes of both trunk and unbalanced shaker mass. For the calculation of the curves Eqns. 1 and 2 were used with real fruit tree and shaker machine parameters. With those data the trunk amplitude of the simple fruit tree model decreases continuously with increased reduced trunk mass, meanwhile the amplitude of unbalanced mass increases. For larger trees the decreased amplitude won't be enough for a high frit detachment %.

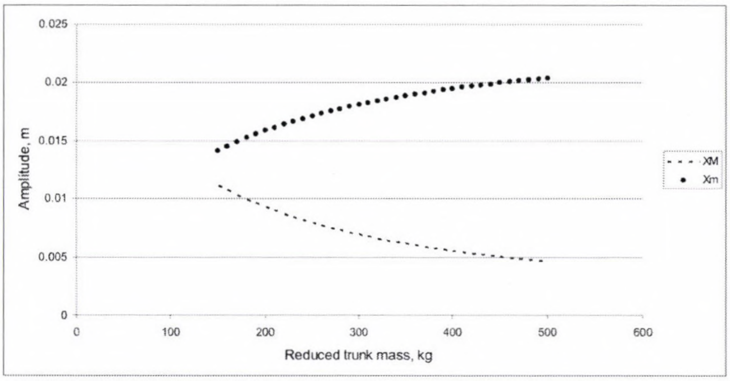

Figure 3. Trunk and unbalanced shaker mass amplitude in function of reduced trunk mass

From Fig. 2 follows that the increased unbalanced mass leads to increased trunk amplitude. This gave the idea to add a second unbalanced mass m_{extr} to the one on the machine (m). As a technical solution m_{extr} is able to move free only along the path $2l_0$ (Fig. 4), so it has no effect on shaking below the unbalanced mass amplitude l_0. Above that it joins to the mass m and increases the trunk amplitude.

On the Fig. 4:

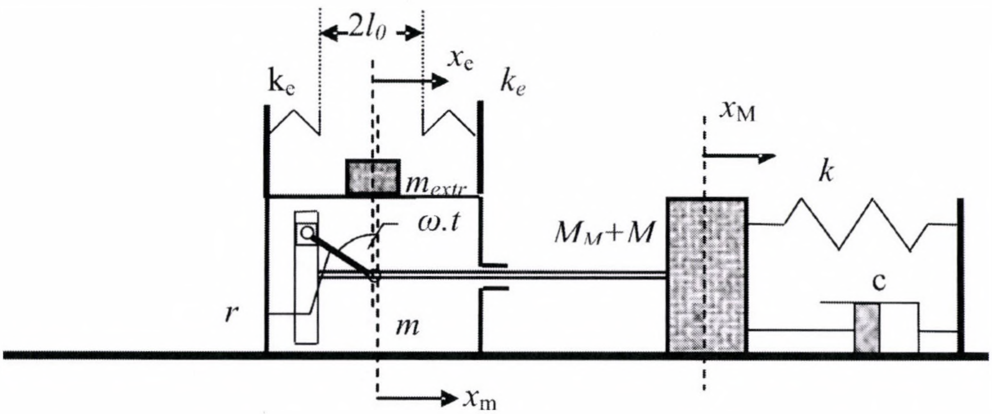

Figure 4. The model of the shaker-tree system with two unbalanced masses.

m_{extr} is the second unbalanced mass, kg

l_0, is the free amplitude of m_{extr}, m

k_e is the spring stiffness of the impacting surfaces between the unbalanced masses, Nm^{-1}

x_M, $\dot{x}_M$ and $\ddot{x}_M$ are the trunk displacement, trunk velocity and trunk acceleration in m, ms^{-1} and ms^{-2} respectively;

x_m, $\dot{x}_m$ and $\ddot{x}_m$ are the displacement, velocity and acceleration of unbalanced mass m in m, ms^{-1} and ms^{-2} respectively;

x_e ,$\dot{x}_e$ and $\ddot{x}_e$ are the displacement, velocity and acceleration of unbalanced extra mass m_{extr} in m, ms^{-1} and ms^{-2} respectively;

The relation between x_M and x_m is as follows:

$$x_m = x_M + r \sin \omega t$$
$$\dot{x}_m = \dot{x}_M + r\omega \cos \omega t \qquad 5$$
$$\ddot{x}_m = \ddot{x}_M - r\omega^2 \sin \omega t$$

Until x_m is smaller than l_0, m_{extr} has no effect on shaking amplitude. It doesn't move, the mass m_{extr} slides free, without contacting m via the springs k_e . The maximal value of it is X_m (Eqn.2)

If X_m is larger than l_0, the springs k_e contacts the mass m_{extr} and it starts to move together with m. The force acting in this case on m_{extr} is:

$$-F_{k_e} = -\frac{1}{k_e}(x_e - l_0 - x_m) \text{ or } -F_{c3} = -\frac{1}{k_e}(x_{dif} - x_m) \qquad 6$$

where $x_{dif} = x_e - l_0$

The kinematic equation for m_{extr}:

$$-F_{c3} = m_{extr}\,\ddot{x}_{dif} \qquad 7$$

Taking in account the effect of all participant elements, and making the necessary replacements, the following differential equations can be set up:

$$(M+m)\ddot{x}_M + c\dot{x}_M + (\frac{1}{k}+\frac{1}{k_e})x_m - \frac{1}{k_e}x_e = (m\omega^2 - \frac{1}{k_e})r\sin\omega t \quad 8$$

From Eqns. (5), (6), (7) :

$$m_{extr}\ddot{x}_e + \frac{1}{k_e}x_e - \frac{1}{k_e}x_M = \frac{1}{k_e}r\sin\omega t \quad 9$$

Expressing the function $x_e=x_e(t)$ from (8) :

$$x_e = k_e(M+m)\ddot{x}_M + k_e c\dot{x}_M + k_e(\frac{1}{k}+\frac{1}{k_e})x_M - k_e(m\omega^2 - \frac{1}{k_e})r\sin\omega t \quad 10$$

Replacing it and its second derived ($\ddot{x}_e=\ddot{x}_e(t)$) into Eqn. 9, the following 4th grade linear inhomogeneous differential equation with constant coefficients appears:

$$A_1 x_M^{IV} + A_2\dddot{x}_M + (A_3+B_1)\ddot{x}_M + B_2\dot{x}_M + (B_3 - \frac{1}{k_e})x_M = (\frac{1}{k_e}r + B_4 - A_4)\sin\omega t \quad 11$$

where

$$B_1 = M+m,\quad B_2 = c,\quad B_3 = \frac{1}{k}+\frac{1}{k_e},\quad B_4 = (m\omega^2 - \frac{1}{k_e})r$$

$$A_1 = k_e m_{extr}B_1,\quad A_2 = k_e m_{extr}B_2,\quad A_3 = k_e m_{extr}B_3,\quad A_4 = k_e m_{extr}\omega^2 B_4$$

We may look for the particular solution of (11) in the following form:

$$x_{Mp}(t) = a\sin\omega t + b\cos\omega t \quad 12$$

Defining their derives $\dot{x}_{Mp}(t), \ddot{x}_{Mp}(t), \dddot{x}_{Mp}(t)$ *és* $x^{IV}_{Mp}(t)$, replacing them into (11), than arranging according the trigonometric functions, the following equation appears:

$$[A_1 a\omega^4 + A_2 b\omega^3 - (A_3+B_1)a\omega^2 - B_2 b\omega + (B_3 - \frac{1}{k_e})a]\sin\omega t +$$

$$+[A_1 b\omega^4 - A_2 a\omega^3 - (A_3+B_1)b\omega^2 + B_2 a\omega + (B_3 - \frac{1}{k_e})b]\cos\omega t = \quad 13$$

$$=(\frac{1}{k_e}r + B_4 - A_4)\sin\omega t$$

Comparing the two sides of (13) and arranging them to a and b:

$$D_1 a + D_2 b = D_0$$
$$-D_2 a + D_1 b = 0 \quad 14$$

In the above system of equations

$$D_1 = A_1\omega^4 - (A_3+B_1)\omega^2 + (B_3 - \frac{1}{k_e})$$
$$D_2 = A_2\omega^3 - B_2\omega \quad 15$$
$$D_0 = \frac{1}{k_e}r + B_4 - A_4$$

From (14) the missing parameters of (12) :

$$a = \frac{D_0 D_1}{D_1^2 + D_2^2}$$
$$b = \frac{D_0 D_2}{D_1^2 + D_2^2} \quad 16$$

The two parameters of (12) can be replaced by two other parameters:

$$a = X_e\cos\Psi$$
$$b = X_e\sin\Psi \quad 17$$

where X_e is the trunk amplitude when the extra mass is in action. With these

$$x_e = X_e\sin(\omega t + \Psi) \quad 18$$

where:

$$X_e = \sqrt{a^2+b^2} = \frac{D_0}{\sqrt{D_1^2+D_2^2}}$$
$$\Psi = arctg\frac{b}{a} = arctg\frac{D_2}{D_1} \quad 19$$

The effect of the extra mass was studied by replacing real data into Eqns. 1-19. For the calculations below the following values were taken: M = 150-500 kg, m=123 kg, m_{extr}= 29 kg, r = 0.025 m, c= 4000 Ns/m, k= 5,4.E-06 m/N, k_e =4,6.E-06 m/N, l_0 = 0.018 m, ω= 81.7 1/s (f=13 Hz).

The values X_m, X_M and X_e in function of reduced trunk mass M are plotted in Fig. 5.

As it indicates, the trunk amplitude is changing at about 230 kg, when the extra mass comes into action: it increases significantly the trunk amplitude compared to the situation without extra mass.

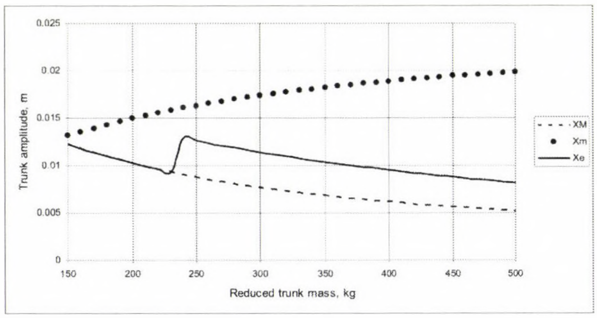

Figure 5. The change of trunk amplitude from X_M to X_e due to the effect of extra mass.

The experimental shaker unit

After setting up the theoretical background of the system, a shaker unit was designed (Fig. 6). As Fig. 6 shows, two identical thick steel discs were put over the bar of a slider crank type shaker. The discs were coupled via four steel tubes which determined the clearance $2l_0$. Changing the tube lengths, different $2l_0$ sizes could be set up. Eight rollers made possible the free move of the coupled discs along the shaker bar. The total mass of these elements was 29 kg.

Note, that the bar mentioned above is part of the unbalanced mass m, it vibrates together with the house of the slider crank.

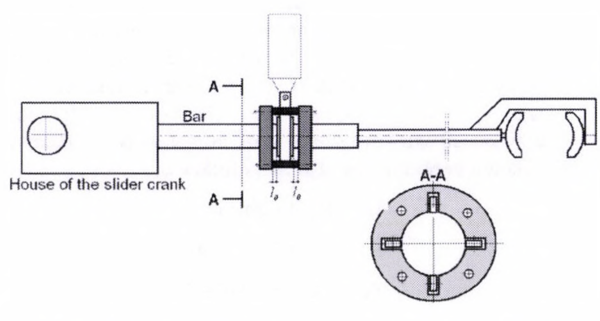

Figure 6. The set up of extra masses to the shaker bar

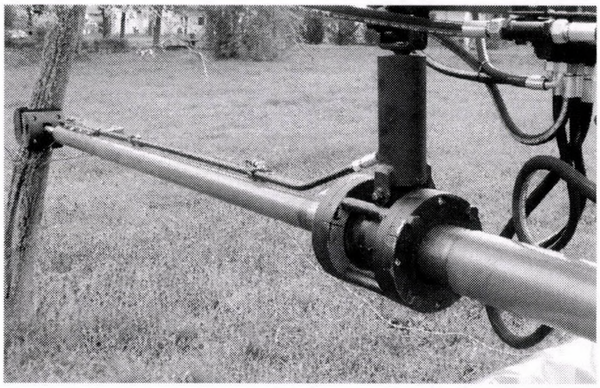

Figure 7. The extra masses on the inertia type shaker

Orchard tests

To control the behavior of the new shaker unit field tests were carried out in a 8 years old cherry orchard, near to Budapest. Two trees with different trunk diameter (135 and 210 mm) were shaken at 65 cm trunk height in 4 arrangements, each at 3 different frequencies. The arrangements were as follows:

1.: no extra mass on the bar, 2.: the extra mass is fixed to the bar (no separate moving of it), 3.: the clearance l_0 was set to 15 mm, 4.: the clearance l_0 was set to 30 mm. The frequencies

for each arrangement on both trees were chosen between 10 and 16 Hz. For each test the shaking frequency and the acceleration amplitude was recorded.

The reduced masses M of the two trees in test were calculated using the method, described by Láng in 2008, which gave for M_1 =280 kg and M_2=360 kg.

Result and discussion

The comparison of calculated and test results was made at 13 Hz shaking frequency. The calculated amplitudes were transformed in acceleration amplitudes using Eqn. 4.

All the different measured data were transformed to 13 Hz value using linear interpolation (Fig. 8). The interpolated values of the 3 repeats at every setup were than averaged (Table 1.).

The data indicate that the acceleration of tree no.1 is almost not influenced by the extra mass: much the same result at no mass, at 15 and 30 mm clearance. It is different for the tree no.2: at no mass and at 30 mm clearance the acceleration is similar; at 15 mm clearance it increases significantly (Fig. 9). With the above fruit tree and shaker machine parameters the effect of the extra mass starts at about 347 kg reduced tree mass.

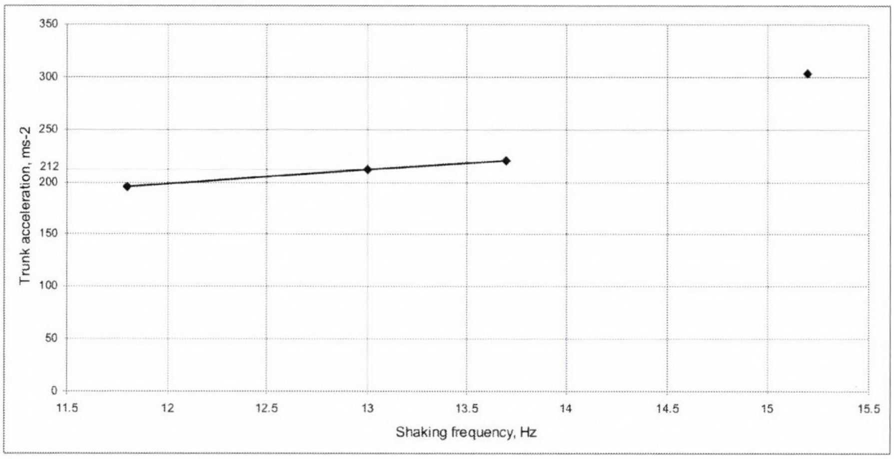

Figure 8. Linear interpolation of measured data to get the trunk acceleration at 13 Hz shaking frequency

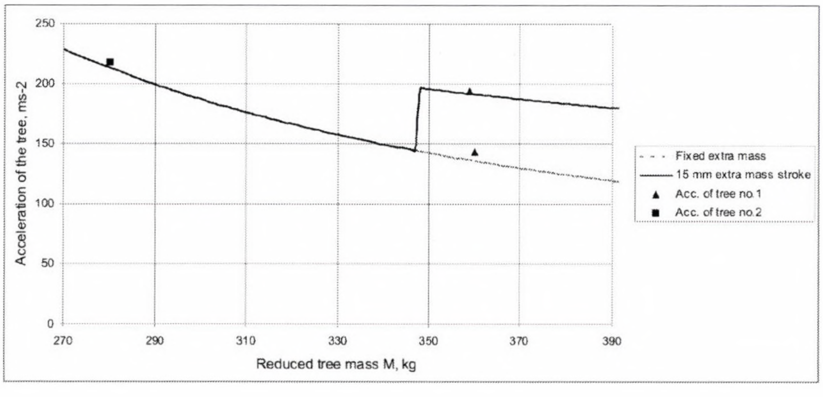

Figure 9. Calculated acceleration vs. tree mass curves and measured acceleration values on the trunk of the two trees.

Table 1. Average accelerations in ms^{-2} at the different test arrangements at 13 Hz shaking frequency

Arrangement	Without m_{extr}	l_0 =15 mm	l_0 =30 mm	l_0 =0 mm
Tree no.1, *Φ135mm*	213	209	218	245
Tree no.2, *Φ210mm*	145	198	147	204

Conclusion

The theoretical results, based on a kinematical model, as well as the orchard tests carried out on two different size cherry trees have shown, that an extra unbalanced mass increases the amplitude and acceleration of larger trees meanwhile the shaker input to the smaller trees remains unchanged. In the orchard tests the reduced mass of the smaller tree was 280 kg, the larger one 360 kg. The diagram of the kinematic model has shown that the 29 kg extra mass starts to increase the unbalanced mass of the slider crank type shaker at about 347 kg reduced tree mass. As a result of the above investigations it may be concluded, that the expansion of a slider crank type shaker by an extra unbalanced mass is a simple but useful method to achieve high detachment rates even at larger trees in orchard, without changing the shaker machine setup.

Acknowledgements

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