Modelling and comparing two canopy shapes using FEM

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Summary: Central leader and Vase form canopy models were built using FEM. Their main characteristics were chosen to be the same. The models were virtually exposed to the effect of steady-state horizontal forced vibration in the frequency range of 0–20 Hz. Acceleration-frequency curves were calculated and drawn to find the best frequency values for the effective detachment and also to see the acceleration differences in the limbs. For the same purpose the direction of shaking was also changed. It was found that for the Central leader canopy shape multidirectional shaking would bring uniform detachment while for the Vase form trees also the unidirectional shakers were appropriate. The acceleration achieved for the Vase form models were much higher than for the Central leader type. The acceleration-frequency curve of the shaker unit can be used to find the best frequency for shaking.

Key words: fruit tree, modelling, FEM, limb shape, shaker harvesting

Introduction

Mechanical shaking of the tree is the most widespread harvesting technology for stone fruits. Both, limb and trunk shaking are practised. In the first case more main branches must be shaken. This method is slower, but the removal is more perfect. It also causes less damage to the tree.

For shaking the trunk no more then about 10–15 seconds are needed for clamping and shaking for each to detach most of the fruits.

The shakers are mostly of inertia-type, whereby oscillating masses are attached directly to the trunk of the tree or through a light weigh rod. The oscillation can be achieved basically either by slider-crank mechanism or by counter-rotating masses. When the shaker unit is connected to the tree via the rod, only one direction oscillation can be achieved. If the shaker unit with the counter-rotating mass is attached directly to the trunk, multidirectional shaking can be achieved. The advantage of this later is that the whole tree is equally shaken in all direction.

In the harvesting practice large variation is noticed concerning removal at different parts of the limb even at multidirectional shaking. Explanation for this might be among others the diversity in geometrical size and structure of the limb. Being a multi-mass dumped swinging system it has many natural frequencies. Ideally, the shaking should be occur at different frequencies to get perfect harvesting. To find optimal shaking frequencies, *Yung & Fridley* (1975) created a finite element tree model. It consisted of a trunk and two branches, each supporting fruit. Natural frequencies, mode shapes, dynamic internal stress and vibration response of the complete tree structure were evaluated for that part of tree at steady-state forced vibration. *Liang* et al. (1971) and *Hussain* et al. (1975) found that the tree must be shaken at several frequencies to develop vibrations throughout the tree.

In this paper two commonly grown cherry tree shapes are compared: a Central leader type (*Hrotkó* et al., 1999) and one of Vase form from the point of view of optimal shaking frequencies and to help the decision between canopy shapes and shaker harvester. For this purpose – different to the models of *Yung & Fridley, Liang* et al. & *Hussain* – we built whole trunk-limb finite element dynamic models. This way, we were able to study the real natural frequencies of the main structural elements of the tree and the effect of a steady-state forced vibration in two horizontal directions. Field experiments were carried out to test the model results.

Material and method

Finite element model of a Central leader *(Fig 1)* and a Vase type *(Fig 2)* cherry tree was built of trunk and straight primary limbs. To be able to compare the two structures most of the characteristics were chosen to be equal. Both were symmetrical around their central axis. Both structures consisted of approximately 10 cm long cylindrical elements. The diameter of the cylinders changed: for the trunk 0–V2 and 0–C2 it was 20 cm, for the main limb C2–C5, V2–V3 and V2–V4 it was 16 cm, above the nodes C5,V3,V4 it was 6 cm. This way at any height the diameter of the elements in the two models was the same. The total height of the model trees was 2.21 m, their total mass 102.5 kg at a density of $1000 kg/m^3$.

Young's modulus was chosen uniformly for all part; $E = 1 \cdot 10^8 N/m^2$. The Poisson's constant was set to 3.57 for each element. Considering results of earlier field experiment (*Láng*, 2002) linear dumping was chosen throughout the model; the value of Lehr's dumping was set to 0.2.

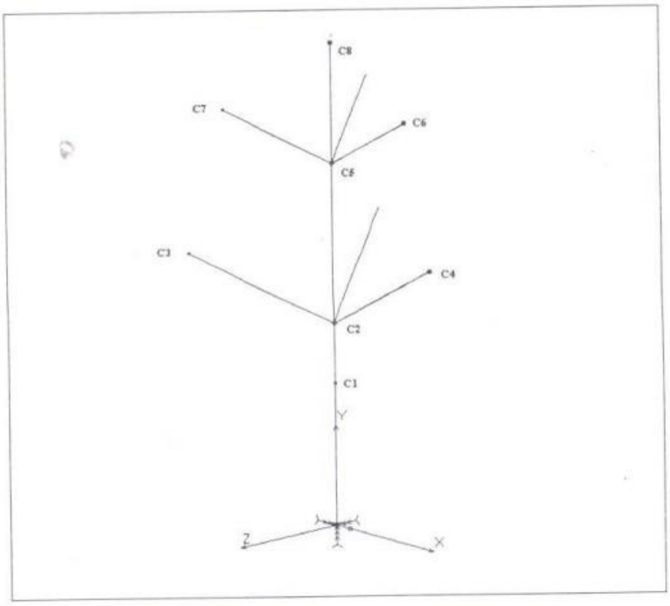

Fig. 1. Model of a central leader type cherry tree

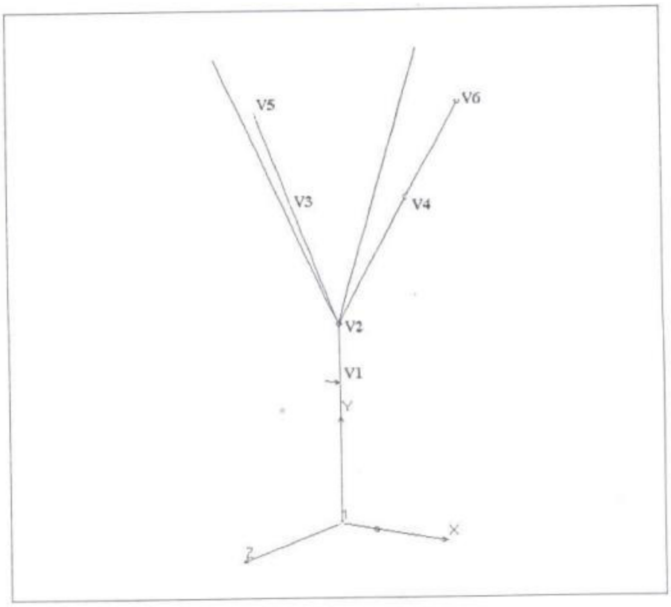

Fig. 2. Model of a vase type cherry tree

The Central leader model consisted of a central trunk and of three main branches in two levels symmetrically distributed. Their position to the horizon was 30°. The branches C4 and C6 stand in the *xy* plain.

The Vase type model was constructed of a trunk and of four main branches, two of them in plane *xy*, two in plane *yz*, standing in 60° to the horizon.

The two finite element models were virtually exposed to the effect of steady-state horizontal forced vibration in different direction of the following form:

$$F_g = F_0 \cdot \sin 2 \cdot \pi \cdot f \cdot t \qquad (1)$$

Were F_0= 3000 N is the maximal force,
$0<f<20$ Hz is the chosen frequency range.

In the case of Central leader type model the excitation was first carried out in direction *x*, then in 30^0 to the direction *x*. This way we had branches shacked in their own plane, perpendicular and in 30° to it.

The vase form model was first exposed to forced vibration in direction *x* then in 45° direction to *x*. This way again, we had branches shaked in their own plane, perpendicular and in 45° to it.

To get comparable results of real values, field experiments were carried out on Central leader and Vase type cherry trees after harvest (no fruit on the trees). The geometrical sizes of the samples were similar to those of the models.

Accelerometers were fixed on different parts of the trees. Their stems were quickly pre-stressed by a force of approximately 3000 N and released. The acceleration versus time curves were processed using FTT method to determine the natural frequencies of the examined parts.

Result and discussion

The finite element method makes possible the calculation of the system's natural frequencies for the two type of limb. The first values of them for the Central leader type are shown in *Table 1*. and for the Vase form structure in *Table 2*.

Table 1. Natural frequencies for the Central leader type tree obtained from FEM and from field test

Natural frequencies (cycles/sec)	
FEM	Field test result
1.70	1.56
3.98	4.68
5.32	5.47
6.54	
7.27	
7.28	7.81
10.03	
10.08	10.15
11.50	10.93
13.48	14.06
	14.84
	15.62
	18.75

Fig 3. shows the acceleration/frequency curves of the most important nodes on the Central leader type tree model. The direction of shaking here was parallel to the *x*-axes. There are two maximums in most of the curves: at about 5.3 Hz and at about 13.5 Hz. The highest acceleration values were calculated for the top of the limb (C8) and for C3, which is at the end of the branch standing in 60° to the direction of shaking. For the branch in the direction of shaking the frequency of maximal acceleration is at about 10 Hz (C4).

Table 2. Natural frequencies for the Vase type tree obtained from FEM and from field test

Natural frequencies (cycles/sec)	
FEM	Field test result
1.61	1.56
4.05	3.91
5.76	
6.89	
8.26	8.59
	10.15
12.19	10.94
14.04	13.30
	15.62
	17.18
	17.68

Fig. 4. presents the acceleration curves of the same model but here the direction of forced vibration is 30° to the axes x. Now, the highest acceleration was calculated at the end of the branch perpendicular to the direction of shaking (C3). The shape of the acceleration versus frequency curve of the branch C4 has changed: its maximum keeps from 10 to 13.5 Hz. The two acceleration peaks are at the same frequency values as on *Fig. 3*.

On *Fig. 3* and *4* all possible acceleration varieties for the nodes examined are present. *Table 3* shows their values at the frequencies 5.3 and 13.5 Hz in both direction of excitation.

Regarding the values at 13.5 Hz excitation: because of symmetrical reasons at the peak (C8) in both cases the value is the same. There is not much difference between C7 and C6. Larger differences can be found between the accelerations of C3 and C4: it makes almost 30%. It means to achieve uniform detachment around the tree multi-directional shaking should be applied. The optimal frequency is where the curve C1 starts to decline. To find it the shaking frequency has to be increased and monitored on the shaker device.

For the Vase type model the acceleration versus frequency curves are shown in *Fig. 5* and *6*. On the *Figure 5*

Table 3. Node acceleration values in ms^{-2} at 5.3 and 13.5 Hz excitation in direction x and 30° to x

	Excitation in direction x		Excitation in direction 30^0 to x	
Nodes	5.3 Hz	13.5 Hz	5.3 Hz	13.5 Hz
C3	35	170	35	185
C4	45	120	40	135
C6	125	160	135	160
C7	140	150	120	145
C8	170	180	170	180

the direction of shaking is x. For the tip of the main branches V6 in the xy plane and V5 in the yz plane there are two frequency peaks, at the higher of them also the V3 and V4 nodes reach their maximum acceleration.

When shaking in direction z the curve of V6 would changes place with the curve V5, similarly V4 with V3.

Some change can be noticed when the direction of shaking was turned 45° to x as *Figure 6* shows it. Although the peaks of curves for V5 (the same as V6) and V4 (the same as V3) are approximately at the same frequencies but their acceleration values are different.

On *Fig. 5* and *6* all possible acceleration varieties for the nodes examined can be found. *Table 4* shous their maximums. It looks clear that shaking the trees in direction 45° to x axes all the 4 limbs are shaken uniformly. In the worst case (shaking in direction x) the difference in acceleration of V3 and V4 is less than 13%. Consequently uni-directional shakers can harvest the Vase form trees effectively. The optimal frequency for shaking is here again at the declination of the curve C1. To find it, the shaking frequency has to be increased constantly and monitored on the shaker device.

Conclusion

The comparison of the natural frequencies measured on real trees and calculated for similar size FEM models have shown good similarity. It indicates the model's applicability for the replacement of the trees in vibration studies.

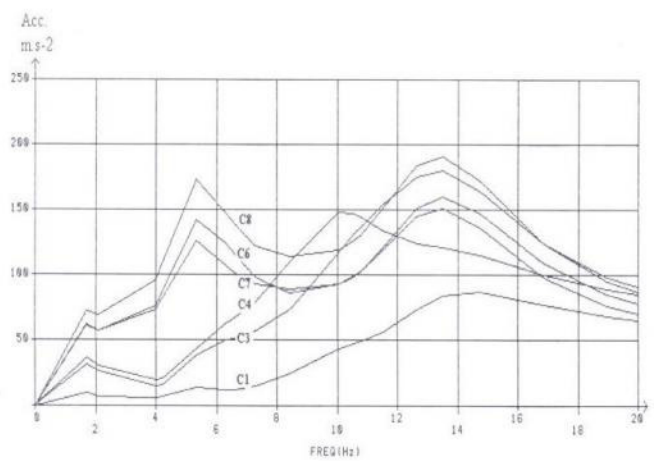

Fig. 3. Acceleration-frequency curves of the nodes of Central leader type model. Direction of steady-state forced vibration: x

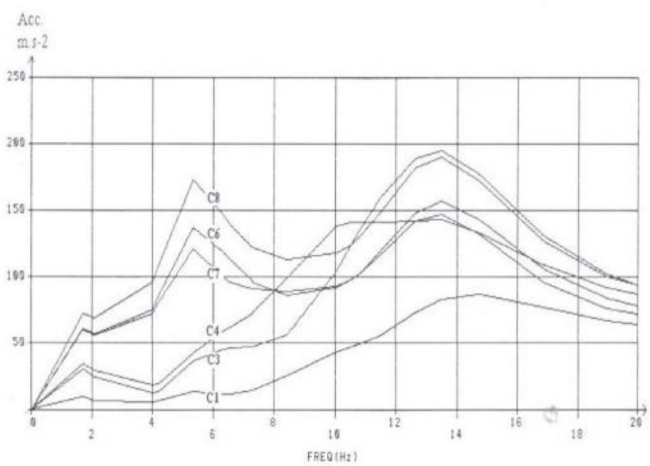

Fig. 4. Acceleration-frequency curves of the nodes of Central leader type model. Direction of steady-state forced vibration: 300 to x

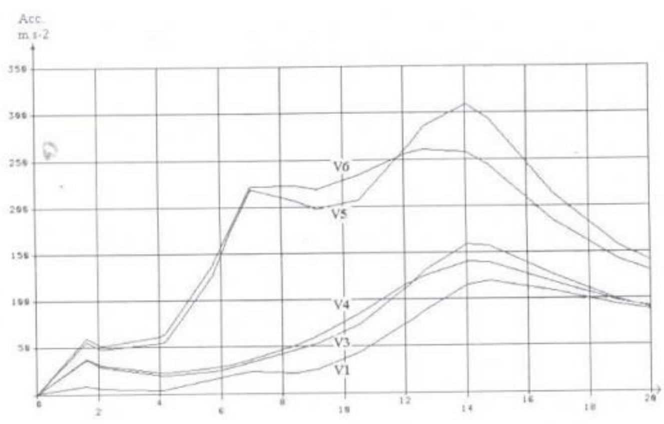

Figure 5. Acceleration versus frequency curves for the Vase type model. Direction of shaking: x

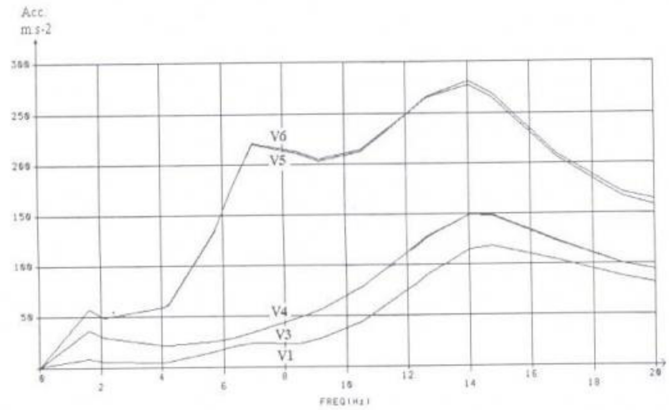

Figure 6. Acceleration versus frequency curves for the Vase type model. Direction of shaking: 450 to x.

Table 4. Node acceleration values in ms^{-2} at 7.0 and 14.0–14.5 Hz excitation in direction x and 45° to *x*

	Excitation in direction *x*		Excitation in direction 30^0 to *x*	
Nodes	7.0 Hz	13.8–14.5 Hz	7.0 Hz	13.8–14.5 Hz
V3	30	160	35	150
V4	35	140	35	150
V5	215	310	220	280
V6	220	210	220	280

Shaking virtually the FEM models in the frequency range of 0–20 Hz made possible to calculate and plot the acceleration response of their most characteristic nodes. At the maximums of the frequency-acceleration curves, the detachment of the fruit would be the most probable: those can be regarded as optimal shaking frequencies.

Virtual multi-directional shaking of the models has shows how the direction of excitation influence the acceleration values of the nodes examined.

For the Central leader canopy shape differences of 30% were found. It means the direction of shaking should change during harvest to achieve uniform acceleration throughout the limb. For this kind of tree shape, multi-directional shakers are recommended.

For the Vase form canpoy the differences were much lower. In this case the uni-directional shakers are appropriate.

Comparing the calculated accelerations for the two FEM trees, much higher values were found for the Vase form. It suggests that the fruits from Vase form trees are easier to detach.

The frequency-acceleration curves give also indication on the optimal shaking frequency. It coincides with the frequency where the shaker unit's acceleration starts to decline.

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