DEVELOPMENT OF TECHNOLOGICAL AND TECHNICAL SOLUTIONS FOR MECHANICAL HARVEST OF STONE FRUITS

Milan VELJIĆ
Dragan MARKOVIĆ
Vojislav SIMONOVIĆ

Abstract: *Fruit shakers represent the most important link in the chain of all machines for stone fruit harvesting, picking and transport on the side of technological and technical solutions. This paper shows analysis of kinematic parameters necessary to separate fruitage from the branch. Technical and technological systems of fruit shakers, mainly vibrators and catchers, are shown. Questions related to satisfaction of agronomical demands, quality and economy are analyzed. Solution which is suggested for mechanical stone fruit harvesting is explained in details, as well as directions of further development.*

Keywords*: fruit shaker, vibrator, picking device, economy*

1. INTRODUCTION

Multiple reasons explain necessity of introduction new technologies for fruit harvesting, specially stone fruits. Picking by hand demands big number of human workers which is significant factor in retail price cost analysis. It is necessary to engage between 350 and 600h/ha (hours per hectare) for stone fruit harvesting (cherry, plum, nuts, apricot, olives), depending of variety, planting technology, etc. Hand picking costs are high due a large number of engaged human workers in long period of time. Almost 50% of production costs are related to harvesting and 80% of those is costs for human labor. Harvesting costs are even higher in case of small stone fruits. High yields per tree or per unit of area are also present in modern fruit production. Serbia had around 45.000.000 of plum trees between 2005. and 2008 with total production of 556.000t in 2006., while the number of cherry trees is around 10.000.000 with production of 80.500t in 2006.

Big number of stone fruit trees, high yields and large areas planted with stone fruits, justify necessity of usage of new technical solutions, particularly fruit shakers. Conditions for introduction of mechanical fruit harvesting and more favorable than 10 years ago, due a fact that industrial fruit processing in increased. Also, a very important factor in agricultural production is deadline for finishing certain process, which is especially important in harvest season. Fruit harvesting should be done in optimal period of time, which can be achieved is the fruit is fully mature. These reasons go into favor of mechanical harvesting, since harvesting time is shorter. Compared to cereals harvesting, fruit harvesting time is 100 to 150 times bigger, and harvest costs are 40 times higher.

2. RESULTS AND DISCUSSION

2.1. Fruit shakers application conditions

In order to apply fruit shakers, certain conditions have to be met, and they are divided in three groups acording to:

- terrain
- planting and cutting technique
- fruit variaty.

Terrain has to be without bumps with slight slope with enough space for maneuvering of tractor with fruit shaker. In order to apply fruit shakers bigger row spacing has to be planned, and cutting has to be performed in such easy that branches and shorter and form unique shape of the crown. It is important that fruitage is resistant to impact, with short shank, and with low connection force between shank and fruitage, and that all fruitage has to mature at the same time. Shaker is intended to work in orchards with 6m row distance and 5-6m distance between trees in row. Tree diameter should be max. 150mm, and height at least 1.2m.

2.2. Analysis of fruit shakers and vibrators characteristics

Main division of fruit shakers based on design, tractor attachment is shown on figure 1.

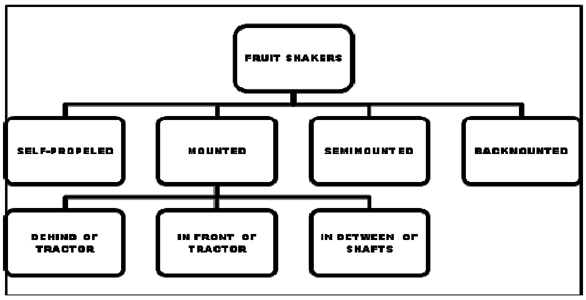


Figure 1. Fruit shakers division

Vibrator with tree catcher has purpose to forward oscillating movement to tree. It is mainly designed as vibrator with constant motion of piston or as piston mechanism with oscillating masses, or vibator with oscillating rotating masses, or as two dependent or independent unbalanced massed. Catcher can be with low tree grip or high grip, so called skeleton branch grip. Vibratory catcher at first stage contains and grips the tree and transfers oscillations from vibrator to the tree. As the result of vibratory oscillations, at the second stage fruitage separation from the branch is performs at the place of weakest link between the shank and the fruitage. In next phase shaken fruitages are collected in earlier positioned special devices placed bellow tree crown. In order to achieve separation of fruitage from the branch, it is necessary to determine oscillating frequency and amplitude of the vibrator at the place of tree constraint. These parameters will provide acceleration of fruitage necessary for separation from the branch.

For kinematic analysis, we adopted horizontal movement of fruitage hanging point, figure 2. We assumed joint connection in point O' and the mass of the shank is neglected, in order to use mathematical equations for movement of pendulum wit horizontal sinusoid movement of hanging point.

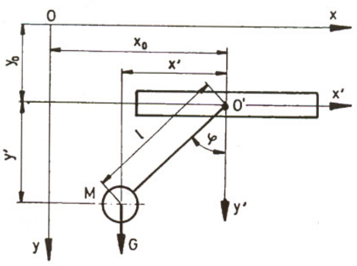


Figure 2. Fruitage movement schematic

Pendulum coercivel motion is achieve by linear movement of hanging point which is fixed in bracket, branch. if we review pendulum general motion equation, and generaly take angle φ as the angle between vertical axes and pendulum axes, it is possible to define differencial motion equations by Lagrange method as well as using direct combination of differencial relative movement equations. As a result, we will get center of gravity motion law as function of rotating angle.

$$\varphi = \frac{a^2}{1 \cdot (\omega^2 - \nu^2)} \cdot \left(\sin \nu t - \frac{\nu}{\omega} \cdot \sin \omega t\right) \qquad (1)$$

a - Ceorcivel force amplitude;
ϑ - Inducement force frequency;
φ - pendulum angle;
l - reduced size of pendulum;
φ = g/l – Possesive frequency oscilation

Average masses of certain fruitage are as follows: cherry 4g; plum, almond, nut 30g: average pendulum reduced sizes 4.8, 4 and 3cm, give following frequencies: for cherry shaking 850-1100 cycles per minute (14-18Hz) at 20-30mm amplitude; for plum, almond and nut 600-800 cycles per minute (10-13Hz) at 40-50mm amplitude.

Theoretical law arrangement of wave spread through tree and branch is very complex due different branches angles, branches masses, curvature, unequal branch diameter, etc. This is why more attention is paid to experimental tests, figure 3.

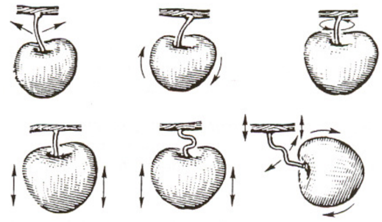


Figure 3. Different fruitage postions during shaking

It is determined, based on research that fruitages which lie in line with shaking direction are easier to fall of the branch, rather than fruitages which lie in direction perpendicular on shaking direction. Almost all fruitages (10%) which are left behind fall of during shake in direction perpendicular on previous shake direction.

Vibrator with piston and oscillating masses, which are commonly used, transfers forces on tree or branch, only in direction of shaker (boom) movement, figure 4. Oscillating frequency is controlled by drive motor speed and at the same time shaker amplitude is freely adjusted to harvesting conditions. Research shows that frequency varies from 10-15HZ and amplitude 12-27mm.

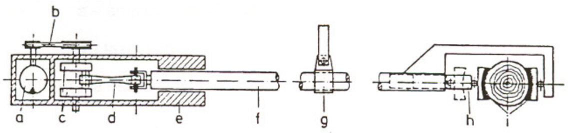


Figure 4. Vibrator with piston and oscillating masses a – hydraulic motor; b – belt drive; c – cam with flywheel; d – arm; e – vibrator housing; f – shaker boom; g – shaker suspension; i – cather scuff

It is determined that at constant amplitude, required power is increasing with frequency increase, up to the point when the tree or the branch enters the area of free electricity frequency, figure 5. At that time power consumption drops, and it rises again when the area of free electricity frequency is passed.

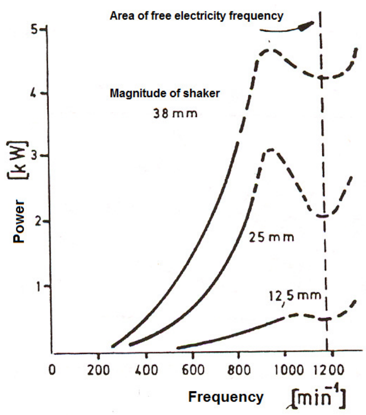


Figure 5. Function diagram of power consumption in correlation with frequency for certain amplitudes

The most common shaker with unbalanced rotating masses is the one where vibrator and gripping device are one entity. Inertial vibrator made by the company "Friday" has unbalanced masses built in its jaws for gripping the tree, which have axes collinear with tree axle, figure 6.

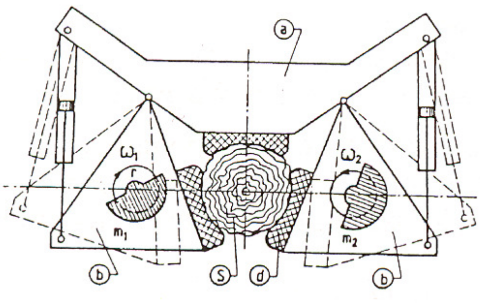


Figure 6. Vibratory by "Friday" company
a – frame; b – moving jaws; d – jaws cover; m_1 i m_2 – rotating masses; ω_1 i ω_2 - rotating masses angle speed; S – tree

They are rotating in opposite directions with different speeds, so the shaking force is always changing direction, which reflect to the tree. Tests show that frequency is between 15 and 17Hz, and the amplitude around 15mm. Construction is compact, but the approach to the tree is more difficult and there is a chance for damaging skeleton branches.
Shakers, as complete system, are generally made out of 2 or 3 subsystems. In a first case it includes vibrator and catcher, and some kind of connecting rod between them which transfers oscillations from vibrator to catcher. In second case, vibrator and the catcher are one entity. When designing a catcher, attention has to be made on allowed pressure on tree skin (p_{dop}) at the place of the hug and grip, which is shown on figure 7.

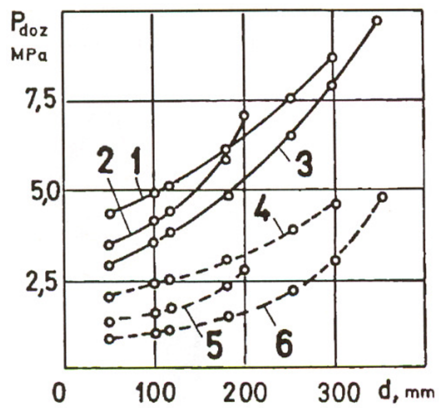
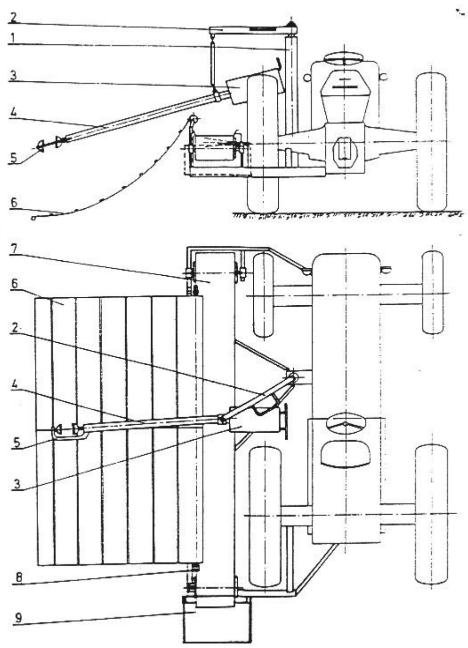


Figure 7. Function diagram of allowed pressure in correlation with tree diameter
1,4 – cherry; 2,5 – almond; 3,6 – plum, apple, apricot; --- radial force direction; - - - tangent force direction

3. OUR RESEARCH

Based on many characteristics and application possibilities for large number of fruit shakers, in different working conditions, Faculty of Mechanical Engineering in Belgrade, started design the most suitable harvesting system for fruit production in Serbia, suitable for the most commonly used tractor, labor, packing type, etc.
It is not justified to observe stone fruit shaker independent from gathering and transport device to boxes or crates. Economical justification of mechanical stone fruit shaker is dependant of damage of fruitage, losses, cleaning systems, number of workers, etc. For some fruitage collecting devices, it is common that they are big in size, no matter if they are pulled or carried by tractor. This characteristic is causing more manipulating time, and more time to go from one tree to another.
When designing a tractor powered fruit shaker, we started from goal to engage as little workers as possible. Our main objective was to avoid extra worker to operate fruit shaker. Instead, tractor driver is taking over control over fruit shaker operation. Fruit shaker had to fulfill demands to have controls close to tractor driver, as well as the tractor driver has to have clear view on shaker and gathering device.
One of the special demand that fruit shaker had to satisfy, besides high level fulfillment of agro technical conditions (minimal damage, losses, application for shaking both tree and branches, multiple grip positions, etc.) was simple design with minimum amount of expensive hydraulic components, in order to have shaker and gathering device for acceptable purchasing price with low maintenance and operational costs.
Fruit shaker with gathering device, figure 8., is developed at Faculty of Mechanical Engineering in Belgrade with company "Morava" from Pozarevac.



Sl.8. Schematic presentation of fruit shaker "Morava"
1-vertucal support-pillar; 2- rotational horizontal support; 3-Vibrator: 4-Boom;
5-catcher; 6- collecting canvas; 7-horizontal transport; 8- frame structure; 9- platform for palet

Vibrator item 3., figure 8., is vibrator with flywheel and piston mechanism. Hydraulic motor transfer power directly to flywheel and cam. Shaker transfers force to tree or branch in boom direction. Catcher, item 5. have movable or fixed jaws with rubber coating in order to prevent damage on tree skin. A movable jaw is operated via hydraulic cylinder, and has a purpose to grip tree or branch.

Shaken fruitage is collected with collecting canvas m 6., figure 8. made from 0.5mm thick PVC. Collecting canvas is assembled from two halves. Wooden bars are position at the canvas end facing towards the tree. Workers are holding canvas by these bars when canvas is wrapped around tree. Tree is located between two canvas halves. Ribs are positioned perpendicular to canvas rolling direction. Ribs are made from hemp rope and stitched into canvas. Ribs have role to prevent fruitages rolling while the canvas is rolled onto drum with axial hydraulic motor. Canvas is folded over the edges fruitages weight which prevents fruitages from falling out from the canvas. Fruitages are transported from canvas to horizontal conveyer item 7, which transports them to rear end where the platform with cases and boxes is located.

Tests were performed at orchard planted with cherry at company “Dzervin” from Knjazevac. Cherry “Hajman” was shaken at 10 years old tree, height of 3m and tree diameter between 90 and 130mm. Distance between trees in row was 3m, and row distance was 4m. Number of tree per hectare was 830, and average yield was 20.000kg. Frequency and amplitude were within the limits of calculated values. Frequency was 15Hz and amplitude was 35mm.

One tractor driver and three workers were engaged during testing. Shaker capacity was 20 trees per hour at the period of 20 testing days, which gives average capacity of 500 to 550kg of cherry per hour. Around 95% of fruitages were shaken during first 2 to 5 seconds. Small percentage of fruitages which was left behind was on tall and long branches.

4. CONCLUSION

Mechanical stone fruit harvesting has significant advantages over manual harvest, due a fact that agro technical terms are shortened and number of hired workers is decreased. Harvest costs are reduced 1.5 to 2.5 times, depending of fruit type, variety, tree condition, etc. Further development of fruit shakers has to be in direction of size reduction, with complete system for shaking, no matter is self propelled or tractor pulled machine, in order to achieve better maneuverability and faster tree approach. More attention has to be paid to development of vibrator and catcher with wider frequency and amplitude range, as well as diverse types of gripping systems. Cleaning system to separate leaves and small branches from fruitages has to be developed. Besides wider application of hydraulics, demand for automatization of mechanical stone fruit harvesting is also present.

REFERENCES

[1] VELJIĆ, M., ČOVIĆ, V., BOJANIĆ, Z., *Odredjivanje optimalne frekvencije uredjaja za otkidanje plodova,* Savremena poljoprivredna tehnika, Vol. 9, Broj 3. Novi Sad 1983. st. 145-149

[2] VELJIĆ, M, I dr., *Mehanizovano ubiranje koštičavog voća,* elaborat, Mašinski fakultet u Beogradu, Beograd 1994. st. 49

[3] NOVAKOVIĆ, V., VELJIĆ, M., JOCIĆ, D., *Optimizacija rešenja tresača voća,* V Internacionalni simpozijum Poljoprivredno mašinstvo i nauka, Aranđelovac, 1985. st. 357-366

[4] VELJIĆ, M., ČOVIĆ V., *Optimizacija parametara vibratora za trešenje voća,* VI internacionalni simpozijum Poljoprivredno mašinstvo i nauka, Požarevac 1988. st. 523-531

[5] ČOVIĆ, V., LUKAČEVIĆ, M., VELJIĆ, M., BOJANIĆ, Z., *Određivanje frekvencije uređaja za mehanizovano ubiranje plodova,* časopis Tehnika-Mašinstvo God. XXXII, Br. 10 1983. st. 9-12

[6] NOVAKOVIĆ, V., VELJIĆ, M., JOCIĆ, D., *Rezultati ispitivanja traktorskog tresača voća,* elaborat, Mašinski fakultet u Beogradu, beograd 1986. st. 17

[7] UROŠEVIĆ, M., *Istraživanje uticajnih parametara ubiranja šljive mašinama vibracionog tipa,* doktorska disertacija, Poljoprivredni fakultet u Beogradu, Beograd 1993.

[8] VELJIC, M., *Prilog odredjivanja ekonomičnosti tresača voća,* 31 JUPITER konferencija, Mašinski fakultet u Beogradu, 2005. st.4.33-4.38

[9] ŽIVKOVIĆ, D., VELJIĆ, M., POZHIDAEVA, V., *Determination of economic indicators for mechanized harvesting of plumbs,* 7th International conference AMO' 2006, Tehnical University of Sofija, Sozopol-Bulgaria, pp 104-108

CORRESPONDENCE

Milan VELJIĆ, Ph.D.
Belgrade University
Faculty of Mechanical Engineering
Kraljice Marije 16
11000 Belgrade, Serbia
mveljic@mas.bg.ac.yu

Dragan MARKOVIĆ, Ph.D.
Belgrade University
Faculty of Mechanical Engineering
Kraljice Marije 16
11000 Belgrade, Serbia
dmarkovic@mas.bg.ac.yu

Vojislav SIMONOVIĆ, BSME
Belgrade University
Faculty of Mechanical Engineering
Kraljice Marije 16
11000 Belgrade, Serbia
vojislav@venividisimonovici.com