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EXPERIMENTAL MODULAR EQUIPMENT FOR NUTTY FRUITS HARVESTING

Mihai MIREA

Scientific Coordinator: Conf. dr. ing. Adrian ROŞCA

University of Craiova, Faculty of Agriculture and Horticulture, 15, Libertăţii Street, 200404, Craiova, Romania, Phone: 0251.414.541, Fax : 0251.414.541, adrosca2003@yahoo.com

Corresponding author email: adrosca2003@yahoo.com

Abstract

The paper presents experimental modular equipment for nutty fruits harvesting in any orchard size. The main part of the equipment consists in pneumatically shock wave generator that realizes short air shock wave that replaces high velocity wind blast. The described procedure is a non-contact method that determines no damage of the tree trunk/ branches (well-known on tree vibration shaking system). The paper presents the technical possibility to extend this procedure, with an adequate equipment adaptation for nutty fruits harvest in small or larger farms.

Key words: *nutty fruits harvesting, pneumatically shock wave, small farms.*

INTRODUCTION

Nut harvesting operations have to begin with the verification of maturity' degree. The nuts (both the fruit and the pericarp) gradually reach maturity and fall. The fall of the nut type fruit is accelerated by rain, cool nights and wind. The harvesting has to begin at the moment when the nut reaches full maturity and has optimal commercial and alimentary value. Nowadays, in Romania and in other Eastern European countries, the harvesting of the nut type fruit is manually realized. The harvest is obtained by tree branches shaking with a long stick, method that to 25 - 30% broken branches, with significant production decrease for the following years. This harvesting method is considered unproductive, thus is no longer recommended. (Botu, 2001)

Large plantations should use the mechanized harvesting method which requires special machines and very expensive devices consisting of hydraulic or mechanical shaking vibrators. Depending on the size and productivity, these kinds of specialized machines are very expensive. Such a harvesting system is efficient only for nut or hazelnut plantations of 40 ÷ 60 hectares.

To harvest middle size orchards with drop fruits (apples, pears, plums, cherries, walnuts) Mechanic Rope Shaker Device is used. This device can be easy assembly at front or rear PTO on every tractor (power starting from 15HP) with tree-point linkage category 1 (Figure 1). Compared to the conventional ladder principle, tree shaking is more than 50% faster when using the patented telescopic handle for fixing the rope onto a branch.

Figure 1. Mechanic rope shaker device

A Multi Purpose Orchard Shaker Power Plant is well-known for large orchards fruits harvest. (United States Patent; Patent Nr.: 5 .247.787)

This harvesting machine for nuts and stone fruits includes an articulated body with a front part and a back part. A tree shaker head is detachable and couples to the front part of the harvesting machine by a C - frame mount. The articulated body with a low clearance provides necessary maneuverability in an orchard environment, while permitting the harvesting machine with the shaker head detached, to function as a general purpose orchard machine for mowing, spraying, brush clearing and other associated tasks. Specialized machinery for these tasks is no longer necessary. Actual machines or modular equipment for large orchard fruits harvesting are based on this patent.

For middle size orchards cider fruits, for small rows upper 4m, or small trees, a Hydraulic Trunk Shaker is recommended (www. Feucht - obsttechnik.de). This modular equipment can be mounted on any tractor with minimum power 50HP (Figure 2). Its easy handling is based on his small weight and big clamps with 180^0 grippers revolving and maximum operational diameter up to 220mm; no protection insurance of the trunk' surface is necessary; small shaking moment on tree-ground. (www. Feucht - obsttechnik.de)

Figure 2. Hydraulic Trunk Shaker

For middle or large size orchards a Hydraulic trunk shaker for half standard trees (Figure 3) is widely recommended. To operate this modular equipment minimum tractor power 60HP is necessary. Suspended by 2 chains, the shaker head is independent from the tractor frame; two support points of the shaker head are mounted on a parallelogram so it reaches a maximum 2,5m swerve; the tightening of the tree's trunk can be modified from 0,3m to 1,3m high; Due to very low amplitude vibration movement, young trees shaking is possible, and the shaker head protect the trees and their roots. It is possible to shake trees with a wide range of diameter, the adjustment being done by the operator, depending on orchard specifications (www. Feucht - obsttechnik.de).

Figure 3. Hydraulic trunk shaker for half standard trees

For larger orchards is recommended Hydraulic Telescopic Shaker (Figure 4). To operate this modular equipment a tractor with minimum power 60HP is necessary. Suspended by 4 chains, the shaker head is independent from the tractor' frame; the omnidirectional vibration masses are driven by two hydraulic engines which offers a full dynamism at the starting up. The telescopic shaker drives straight down the tree row shaking each tree as it goes, this provides more efficiency and avoids damaging the field. (www. Feucht - obsttechnik.de)

Figure 4. Hydraulic Telescopic Shaker

For each modular equipment or specialized machine described above, a harvester umbrella must be a necessary accessory (Figure 5). (www. Feucht - obsttechnik.de)

Figure 5. Umbrella harvester with shaker

During harvesting with these machines, the vibrations cause severe damage to the roots of the tree, and the scratching of the tree trunk causes the premature drying of the tree. (Botu, 2001)

An important role in nuts harvest is held by wind action, whose intensity determines the falling of the nuts. (Botu, 2001)

Unconventional and ecological experimental equipment *Modular Equipment for Nuts Harvesting by Pneumatic Impulses – MEHPI* was designed and made. The prototype tests proved that this experimental equipment can *replace the effect of strong winds blasts, with orientated air shock waves* (Figure 6).

This equipment realizes nuts harvest by branches shaking *with no direct contact with the tree. MEHPI* is mounted on a rigid metallic support placed on the front side of a tractor U650M, that permits operator' to control and to correct the tractor's position to the trees that must be harvested. The *MEHPI*'s main operational component is represented by 4 pneumatic impulses device (*PID*), whose relative direction can be modified according to tree's branches position.(Roşca, 2003)

Figure 6. Modular Equipment for Nuts Harvesting by Pneumatic Impulses - *MEHPI*

In principle, each *PID* consists in 8dm^3 capacity vessel with a special fast pneumatic valve due to the compressed air (initially stocked in the vessel) is discharged in sonic velocity range. The *PID* operation needs 3…10bar compressed air supply source (tractor's compressor or supplementary compressor for pressure supply up to 10bar).(Roşca, 2003; Roşca et Roşca, 2005; Roşca et al., 2006)

MATERIAL AND METHOD

PID equipment operation, usually called air cannon / air blaster, is based on the effect of the compressed gas wave shock discharged with high velocity from a storage vessel.(Big Blaster - Martin Engineering; Airchoc - Standard Industrie) During this fast process, the gas flow has high rate pressure variation; therefore there is no heat exchange with the outside environment, and the flow process is considered adiabatic. For compressible fluids, the Bernoulli equation for adiabatic process is (Roşca et Roşca, 2005; Roşca et al., 2006; Roşca et Roşca, 2009):

$$\frac{v^2}{2} + \frac{k}{k-1} \cdot \frac{p}{\rho} = \frac{v_0^2}{2} + \frac{k}{k-1} \cdot \frac{p_o}{\rho_o}, \qquad (1)$$

where p_o and ρ_o are the initial parameter of the gas; p and ρ are the final parameter of the gas; k is the adiabatic coefficient; v_o is the initial gas velocity (in the storage vessel v_o= 0).
When the compressed gas is discharged from a storing vessel (initial parameter p_o, ρ_o, T_o) through a nozzle in the atmosphere (final parameter p_{at}, ρ_{at}, T_{at}), the gas velocity is obtained with relation:

$$v = \left[\frac{2k}{k-1} \cdot \frac{p_o}{\rho_o} \cdot \left[1 - \left(\frac{p_{at}}{p_o} \right)^{\frac{k-1}{k}} \right] \right]^{1/2} \qquad (2)$$

Because the ratio value ($p_{at} / p_o < 0{,}5283$), in the minimum cross section of the convergent nozzle the *critical regime* is realized.
In critical regime, the maximum flow passing through the cross section Q_{max} is obtained, and can be determined with relation (Roşca et Roşca, 2005; Roşca et Roşca, 2009):

$$Q_{max} = 0{,}04042 \cdot S_p \cdot p_o / \sqrt{T_o} \qquad (3)$$

where S_p is cross section area of the convergent nozzle (the convergent nozzle/pipe D_p = 44mm).
For the experimental equipment presented in this paper, it was considered the initial and the final parameters of the compressed air: p_o = 2 - 5 bar; p_{at} = 1 bar; $T_o = T_{at}$ = 293°K; k = 1,4.
The velocity of the discharged pressured air v_{disc} from the storing vessel, and the maximum flow Q_{max} passing through the cross section are given in Table 1.

Table 1. Velocity and maximum flow of the discharged air

p_o [bar]	ρ_o [kg/m^3]	v_{disc} [m/s]	Q_{max} [kg/s]
2	2,84	340,2	0,914
3	3,42	365,8	1,010
4	4,53	407,6	1,364
5	5,72	436,7	1,709

For the experimental equipment presented in this paper, four vessel capacity (C_v = 5, 6, 7, 10 dm^3) were considered.
Knowing the compressed air mass in the storage vessel $m_{vo} = C_v \cdot \rho_o$, with Q_{max} values given in table 1, the vessel's discharging time values (t_{disc} = 14,3…27,2ms) confirm the high velocity impulsive phenomenon.

The theoretical considerations concerning the gas discharge from the stocking vessel take into account the similitude with the flow process into round free jet.

This free jet is a gas current that freely penetrates (with small friction forces restriction) into an environment with the same or different gas. The jet's range is the distance where the kinetic energy of gas is not greater then the viscosity forces and no more swirling flow occur.(Roşca et Roşca, 2005; Roşca et al., 2006; Roşca et Roşca, 2009)

Qualitative and quantitative evaluation of characteristic dimensions of the round free jet permit to determine the main dimensional parameters of convergent - divergent nozzle that is orientated to tree's branches: α - angle of jet action; x_{lim} - jet range; R_{gr} - jet radius (Figure 7).

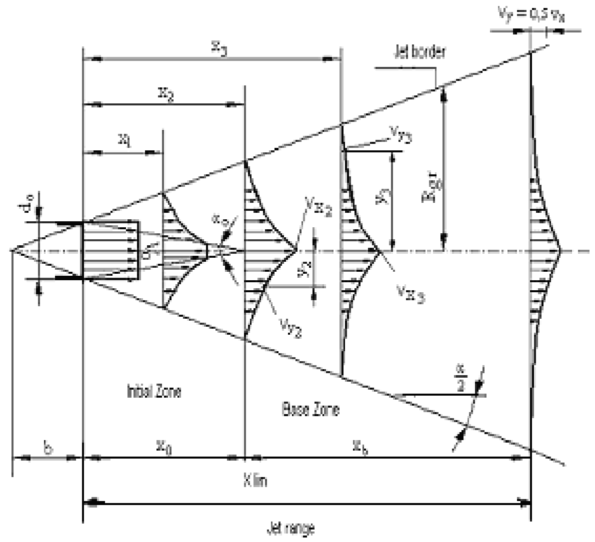

Figure 7. Circular jet geometry

The circular jet's characteristic dimensions are: initial velocity v_o; shape and diameter of the initial discharge nozzle d_o; length of the initial zone x_o; jet range x_{lim}; convergence angle of the initial zone α_o; the enlarging jet border angle α; gas flow in initial section Q_o; jet pole b; jet radius R_{gr}. The initial section of the discharging nozzle is the circular section in which the medium velocity of the jet is realized (the environment velocity v_{env} can be equal to zero, bigger or smaller than v_o; for $v_{env} = 0$, the jet is considered to be free).

The velocity in the jet's axe v_x depends on the initial velocity v_o and by the distance: for $x < x_o$, the velocity $v_x = v_o$; for $x > x_o$ the velocity v_x depends of distance x.

The velocity in the transversal jet section v_y is the velocity at distance x and at the level y; this velocity depends by the velocity v_x and level y, according relation (Roşca et al., 2006; Roşca et Roşca, 2008; Roşca et Roşca, 2009):

$$v_y / v_o = \left[1 - \left(y / R_{gr} \right)^{3/2} \right]^2 , \quad (4)$$

where R_{gr} is the jet's radius limit for $x > x_o$.

Due to the symmetric axial jet law, the impulse has the same value in any section.

Using the notation v_y the velocity in a certain point, the impulse I, and m_o the masse passing through an elementary surface of the jet's section in the unit of time, it is obtained:

$$I = 2\pi \int_o^{R_{gr}} \rho v_y^2 y dy = \pi \rho_o v_o^2 R_o^2 , \quad (5)$$

where the jet's radius limit R_{gr} is obtained with relation:

$$R_{gr} = 3{,}3 \; R_o \left(v_o / v_x \right) , \quad (6)$$

where R_o is the jet's source radius ($R_o = d_o/2$).

The medium velocity of jet v_m is determined knowing that the medium flowing velocity in a section A is obtaining from the continuity equation:

$$v_m = Q / A = Q / (\pi R_{gr}^2) . \quad (7)$$

Because in the initial section the velocity value is obtained with relation

$$v_o = Q / A = Q / (\pi R_o^2) ,$$

using relation (7), it can be obtained

$$v_m / v_o = 0{,}2 \cdot \left(v_x / v_o \right) \quad (8)$$

According circular jet geometry theory (no gas viscosity effect and no shock wave effect), for initial compressed air pressure p_o = 2 - 5 bar, were obtained theoretical results: medium speed in the jet transversal section with equivalent values for wind velocity v_w = 25 - 60 km/h; jet's range x_{lim} = 0,5 - 2,4m; jet border angle $\alpha = 50^o - 62^o$.

Similar values were obtained by using FEM. (Năstăsescu, 2005 ;Roşca et al., 2006; Roşca et Roşca, 2008; Roşca et Roşca, 2009)

An experimental method to determine medium velocity in the jet transversal section with equivalent values for wind velocity (v_{wind}), jet's range (x_{lim}) and jet border angle (α) was set by using Fastec Imaging high speed camera.

To determine these parameters, a fine powder contrast colored was introduced into convergent

nozzle of *PID*'s fast speed discharge pneumatical valve. A white panel with 0,1m horizontal and vertical grids was used.
According to the theoretical values average of the shock wave velocity, the image capturing sequence was set for 500 fps.
The high speed camera MiDAS 4.0 Express Control Software start was simultaneous triggered with the *PID*'s fast discharge pneumatical valve. (Roşca et Roşca, 2008; Roşca et Roşca, 2009)
Shock wave velocity values experimentally determined were 5…11% smaller then the values obtained by theoretical method.
These smaller values confirm that due to high velocity discharge, the gas' viscosity fast increasing determines supplementary friction aerodynamically forces.

RESULTS AND DICUSSIONS

Experimental modular equipment for nutty fruits harvesting presented in this paper, consists in a metallic frame and a pneumatically shock wave generator (Figure 8).
The *metallic frame* is special designed to resist both statically loads during transport and positioning stages, and during harvest operation when impulsive dynamical occurred. (Roşca, 2001; Roşca, 2010)
The metallic frame is composed in mobile carrying device provided with a vertical mobile support (that permits to set operational position up to 5m in high) and a horizontal support (that permits two *PID* mounting).
For nutty harvest in small farm, the mobility of the experimental equipment is realized due to two wheels.
For middle nutty orchards, the metallic frame can be mounted on a 9-15 HP motocultivator, or on a small tractor structure. On the metallic frame can be mounted the pressured gas supplying device (small motor-compressor or pressured gas vessel).
Pneumatically shock wave generator realizes short air shock wave that replaces high velocity wind blast.
Pneumatically shock wave generator is composed in: pressured gas supplying device; a modular compressed gas command circuit; two special *PID.*
In figure 8 is presented experimental modular equipment with an independent compressed gas source consisting in CO_2 pressured vessel, and pressure redactor that realize low pressure supplying up to 5 bar.
It must be noticed that during the equipment testing, due to CO_2 detention, the pressure redactor was freezing.
Thus, pressured CO_2 supplying device has to be utilized with special precautions.
Therefore, for safety operation of this modular equipment, recommended pressured gas supply device are motocultivator or small tractor end shaft, and an independent 6 bar moto-compressor.

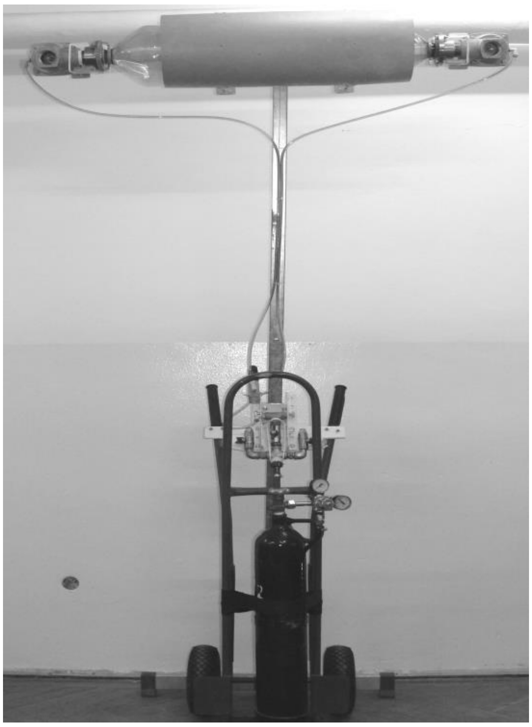

Figure 8. Experimental modular equipment for nutty fruits harvesting

Modular compressed gas command circuit consists in a 3/2 pneumatical valve and Φ8 and Φ12 Gilson pipes that realizes the connections between the compressed gas source and PID.
Rilsan pipe is a versatile plastic material that supports pressured gas or liquid up to 10 bar, at temperature up to 90ºC, and it resists in mineral oil prolonged contact.
To realize the necessary modular functions for transport, mounting and maneuverability of the experimental equipment, all the connections are realized by using fast connections fittings.
It must be noticed that only this 3/2 pneumatical valve type is able to command the PID' in less then 20ms, thus to realize the fast discharge of the PID vessel in sonic velocity range.
Previously it was mentioned that in principle, *PID* consists in small capacity vessel with a fast

pneumatic valve due to the compressed gas (initially stocked in the vessel) is discharged in sonic velocity range.
For experimental equipment described in this paper, was designed a new PID that consists in a plastic material small capacity vessel, and a special fast pneumatic valve (FPV).
To increase the maneuverability during harvest operations, this experimental equipment needs lighter weighting of the compressed gas vessel.
There are well-known the mineral uncarbonated water bottles made in PET.
An innovative idea presented in this paper consists to recover and to recycle any type of mineral water bottles, to be used as compressed gas storage vessel for this experimental equipment PID.
During the tests, four vessel capacity (5, 6, 7, 10 dm^3) were pressurized to determine the maximum pressure and maximum cycles filling that can be supported.
According to the wall thickness, bottle shape and producer' PET specifications, there are types of bottles that resist up to 9bar, and more than 200 cycles with compressed air filling.
During the harvest operations, the bottles are protected by a metallic light panel (Figure 8).
To increase the maneuverability during harvest operations, a special fast pneumatic valve (FPV) was realized.
The special FPV permits both compressed air storage into the vessel, and fast discharge from the vessel when 3/2 pneumatical valve is actuated.
During the season this experimental equipment was made, no fruits harvest is possible.
Therefore, the functional tests were performed indoor.
During these tests, the special PID made for this experimental equipment worked with identical performances with *MEHPI*' PID, confirming the correctness of the new technical design.

CONCLUSIONS

Experimental modular equipment for nutty fruits harvesting presented in this paper, in principle consists in a pneumatically shock wave generator that replaces high velocity wind blast.
This procedure is a non-contact method that determines no damage of the tree' trunk and branches (well-known on tree when vibration shaking harvest systems are used).
Another innovative idea presented in this paper consists to recover and to recycle any type of mineral water bottles, to be used as compressed gas storage vessel for this experimental equipment PID.
During nutty fruits harvest season, further tests are necessary to optimize the operational performances of the experimental modular equipment. Experimental modular equipment was special designed to be used for nutty fruits harvesting in small and middle orchards farms.

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