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AIR SHOCK WAVE VELOCITY ANALYZE OF EXPERIMENTAL EQUIPMENT FOR NUTS HARVESTING IN SMALL FARMS

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Abstract: *The paper presents experimental modular equipment for nuts harvesting in small farms. The main operating part of the equipment consists in a special shock wave generator that realizes impulsive air shock wave able to replace high velocity wind blast. The described procedure is a non-contact method, with no damage effect of the tree trunk/ branches (well-known on tree vibration shaking system). The paper describes the mathematic modeling method calculus for the configuration and geometric dimension of the shock wave, and the results obtained for shock wave velocity during the experimental analyze.*

Keywords: *air shock wave velocity, high speed camera, nutty fruits harvesting, small farms*

1. INTRODUCTION

The nuts gradually reach maturity and the fruits fall with or no pericarp. The rain, cool nights and wind accelerates the nutty fruits falling. The harvest has to be begun in the moment when the nut is reaching full maturity and has optimal alimentary and commercial value. In Romania and in other Eastern European countries, in principle, the harvest is made manually, as the unique method available both in case of single trees or organized plantations. The harvest is realized by shaking with a long stick, method that determine up to 30% broken branches, that cause the crop decreasing for the following years. Considered as unproductive, this harvesting method is no more recommended.

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 ha [1].

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.

For middle or large size orchards a Hydraulic trunk shaker for half standard trees (Figure 2) 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. It is possible to shake trees with a wide range of diameter, the adjustment being done by the operator, depending on orchard specifications [8].

Figure 1. Mechanic rope shaker device

Figure 2. Hydraulic trunk shaker for half standard trees

For larger orchards is recommended Hydraulic Telescopic Shaker (Figure 3). 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 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 [8, 10].

Figure 3. Hydraulic Telescopic Shaker

For each modular equipment or specialized machine described above, a harvester umbrella must be a necessary accessory (Figure 4) [8].

Figure 4. Umbrella harvester with shaker

2. EXPERIMENTAL EQUIPMENTS FORNUTTY FRUITS HARVEST BY IMPULSIVE AIR SHOCK WAVE

During harvesting with these machines, the vibrations cause severe damage of the roots of the tree, and the scratching of the tree trunk causes the premature drying of the tree. An important role in nuts harvest is held by wind action, whose intensity determines the falling of the nuts [1].

An ecological and unconventional nut harvesting method was proposed to replace wind blasts effect by *impulsive air shock wave* with adjustable intensity and direction, which are similar with the velocity and orientation of strong wind blasts.

To harvest large size nutty orchards, *Modular equipment for nuts harvest by pneumatic impulses-MEHPI* (Figure 5) was special design and made by Unconventional Equipment and Technlg. for Agricultural - Food Industry Laboratory, within the Faculty of Horticulture in Craiova. *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 [5].

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 [5].

The *MEHPI* prototype tests realized in middle and large size nutty orchards proved this experimental equipment can *replace the effect of strong winds blasts, with orientated impulsive air shock waves*.

This experimental equipment realizes nuts harvest by branches shaking *with no direct contact with the tree* [5].

Figure 5. Modular Equipment for Nuts Harvesting by Pneumatic Impulses – *MEHPI*

For small nutty farms and irregular nutty orchards, within Unconventional Technologies and Equipment for Agricultural - Food Industry Laboratory, a *Portable modular equipment for nutty fruits harvesting – PEHPI* was made. *PEHPI* consists in a metallic frame and a pneumatically shock wave generator.

The *metallic frame* is special designed to resist both statically loads during transport and positioning stages, and during harvest operation when impulsive dynamical occurred. For nutty harvest in irregular orchards, *PEHPI*'s mobility is realized due to two small wheels (Figure 6).

For middle nutty orchards, the metallic frame can be mounted on a 9-15 HP moto-cultivator, 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 - PWG* realizes impulsive air shock wave that replaces high velocity wind blast. *PWG* is composed in: pressured gas supplying device; a modular compressed gas command circuit; two special *PID*.

In figure 6 is presented *PEHPI* with an independent compressed gas source consisting in CO_2 pressured vessel, and pressure reductor 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 could freeze.

Thus, pressured CO_2 supplying device has to be utilized with special precautions.

Therefore, for *PEHPI*' safety operation, recommended pressured gas supply device are motocultivator or small tractor end shaft, and an independent 6 bar moto-compressor.

Figure 6. Portable modular equipment for nutty fruits harvesting – *PEHPI*

Modular compressed gas command circuit consists in 3/2 pneumatical valves which are able to command the *PID* in less then 20ms, thus to realize the fast discharge of the *PID*'s vessel in sonic velocity range.

MEHPI's main operational component is composed in 4 *Pneumatic Impulses Device – PID*. In principle, each *PID* (figure 7) consists in 8dm^3 mettalic vessel with a special *Fast Pneumatic Valve* - *FPV* due to the compressed air (initially stocked in the vessel) is discharged with sonic velocity.

The *MEHPI*'s *PIDs* operation needs 3…10bar compressed air supply source (up to 10bar tractor's compressor or supplementary motor-compressor). [5]

Figure 7. PID with metallic vessel

PEHPI's main operational component is composed in two new designed *PID*, that consists in a plastic material small capacity vessel, and a special *FPV* (Figure 8). To increase *PEHPI*'s maneuverability during harvest operations, *PEHPI* needs lighter weighting of the compressed gas vessel. There are well-known the mineral uncarbonated water bottles made in PET. An innovative idea 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.

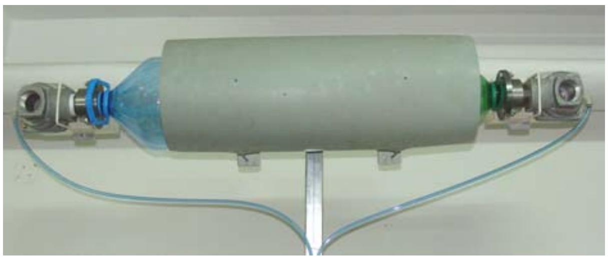


Figure 8. PID with plastic material vessel

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.

To optimize the harvest process and to avoid dangerous dynamic bending of the tree' branches, the velocity of *impulsive air shock waves* have to be precisely determined and controlled.

3. THEORETICAL CONSIDERATIONS CONCERNING SHOCK WAVE VELOCITY

Usually called air cannon / air blaster, *PID* is based on the effect of the compressed gas wave shock discharged with high velocity from a storage vessel [9,12]. During this fast process, the gas flow is characterized by high rate pressure variation; therefore there is no heat exchange with the outside environment, and the flow process can be considered adiabatic. For compressible fluids, the Bernoulli equation for adiabatic process is:

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

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).

In slow / static adiabatic transformations, which are isentropic (the entropy S is constant) [3, 4, 5].

The dynamic adiabatic transformations are irreversible (the entropy increase due to the internal heat stored in gas due to viscosity forces). Neglecting the viscosity force, this motion can be considered isentropic (admissible hypothesis for gas blaster discharge phenomena) [3, 4, 5].

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 determined with relation [3, 4, 5]:

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

Because the ratio (p_{at} / p_o) < 0,5283, in the minimum cross section of the convergent nozzle/pipe the critical regime is realized, and the maximum flow that is obtained (passing through this cross section) Q_{max} can be determined with relation [3, 4, 5]:

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

where S_p is cross section area of the convergent pipe / nozzle (in the example presented in this paper the convergent nozzle / pipe D_p = 44mm).

Considering the initial and the final parameters of the gas (p_o = 3 -10 bar; p_{at} = 1 bar; T_o = T_{at} = 293°K; k = 1,4), the velocity v of the pressured air discharged from the storing vessel, and the maximum flow Q_{max} passing through the cross section S_p are given in Table 1.

Knowing that the compressed air mass in the storage vessel (C_v - vessel capacity) is $m_{vo} = C_v \cdot \rho_o$, and using the Q_{max} values given in table 1, the vessel's discharging time values t_{disc} = 0,0265 s confirm the impulsive phenomenon [3, 4, 5].

Table 1. Velocity and maximum flow of the discharged air

p_o [bar]	ρ_o [kg/m^3]	v [m/s]	Q_{max} [kg/s]
3	3,57	398,1	1,077
4	4,76	438,5	1,435
5	5,95	465,7	1,795
6	7,14	485,5	2,153
7	8,33	500,9	2,512
8	9,52	511,8	2,871
9	10,71	523,6	3,230
10	11,89	532,7	3,590

This theoretically discharging time values t_{disc} is equivalent with the FPV fast discharge characteristic [11].

The theoretical considerations concerning the gas discharge from the stocking vessel take into account the similitude with the flow process into round free jet. Qualitative and quantitative evaluation of characteristic dimensions of the round free jet permit to determine the main dimensional parameters of convergent - divergent nozzle / pipe that is able to be directioned to tree's branches: b - distance from the jet pole; x_o - length of initial zone; α - angle of jet action (Figure 9) [3, 4, 5].

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 $v_x = v_o$, and 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, depends by the velocity v_x and level y

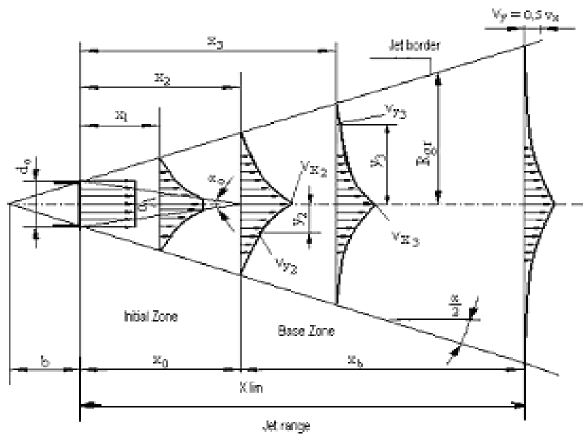


Figure 9. Circular jet geometry

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

where R_{gr} is the jet's radius limit for $x > x_o$ [3].

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, I the impulse, and m_o the masse passing through an elementary surface of the jet's section in the unit of time, it obtained [3, 4, 5]:

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

where the jet's radius limit R_{gr} is obtained with the relation [3, 4, 5]:

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

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 [3, 4, 5]:

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

Because in the initial section the velocity value is obtained with rel. $v_o = Q / A = Q / (\pi R_o^2)$, using relation (7) we can obtain

$$v_m / v_o = 0,2 \cdot (v_x / v_o) \qquad (8)$$

Using these relations (that take into consideration no gas viscosity effect and no shock wave effect), for initial compressed air pressure $p_o = 3 \div 10$ bar in the storage vessel, were obtained theoretical results for: medium speed in the jet transversal section $v_m = 16,6 \div 55,5$ m/s (equivalent velocity 60 ÷ 200 km/h); jets range $x_{lim} = 0,7 \div 2$m; enlarging jet border angle $\alpha = 53^o \div 67^o$. [3, 5]

4. EXPERIMENTAL CONSIDERATIONS CONCERNING SHOCK WAVE VELOCITY

In order to determine the shock wave velocity a first method that take into consideration the dynamic pressure produced by the *PID* was designed. In principle, the experimental device, consists in a conical nozzle (h = 250mm; $Ø_{max} / Ø_{min}$ = 300/50mm).

The size and the dimension of the conical nozzle were designed according to the values determined with the presented theoretical method (jet range x_{lim}, conical jet border angle α, jet diameter D_{gr} for jet range).

The large base of the conical nozzle is closed with a rigid metallic round flange that permits three Vishay pressure transducers connection.

The pressure transducers are connected with an amplifier device to a data acquisition system. [6]

The small base of the conical nozzle is in direct connection with the *FPV*'s circular nozzle.

The *FPV*'s discharging time (the period between the initial trigger's time of *FPV*, and the moment when the discharged pressure is maximum) was measured [7, 9].

In figure 10 and Figure 11 is presented the dynamic pressure evolutions and the discharging time (shock wave duration) obtained for an initial pressure p_o = 4 bar, and . p_o = 5 bar, respectively.

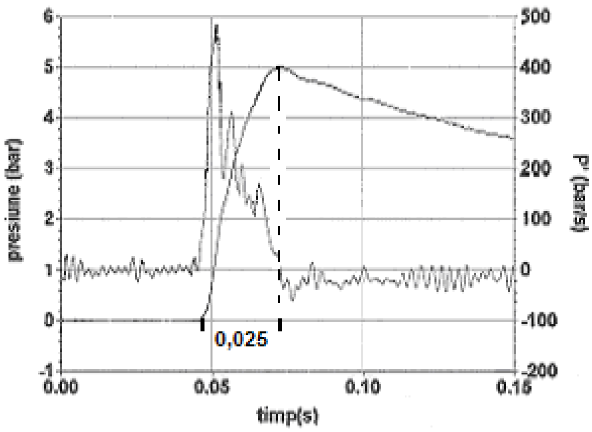


Figure 10. Discharging time for an initial pressure p_o = 4 bar

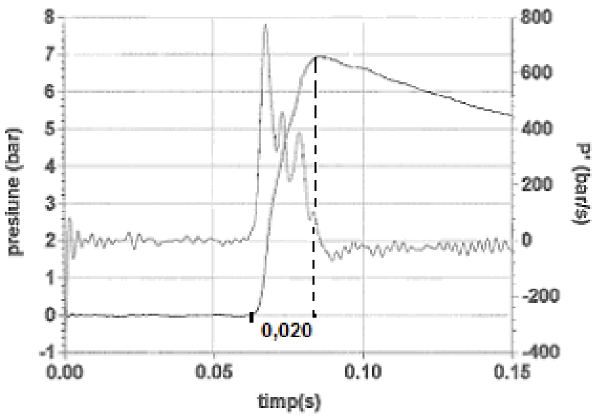


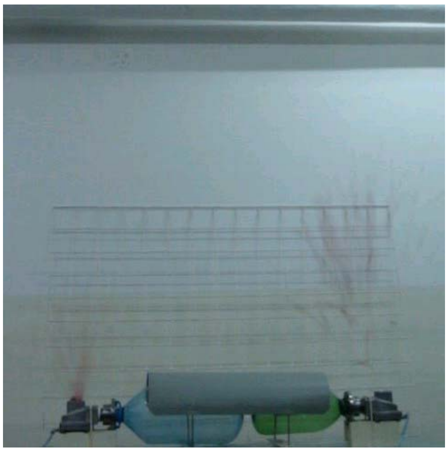
Figure 11. Discharging time for an initial pressure p_o = 5 bar

Table 2. Discharging time, shock wave velocity and equivalent wind velocity

p_o [bar]	t_{dish} [s]	v_{sw} [m/s]	$v_{eq\text{-}w}$ [km/h]
3	0,027	8,82	31
4	0,026	9,26	33
5	0,025	10	36
6	0,022	11,1	40
7	0,020	12,5	45
8	0,017	14,7	53
9	0,013	19,4	70
10	0,010	25	90

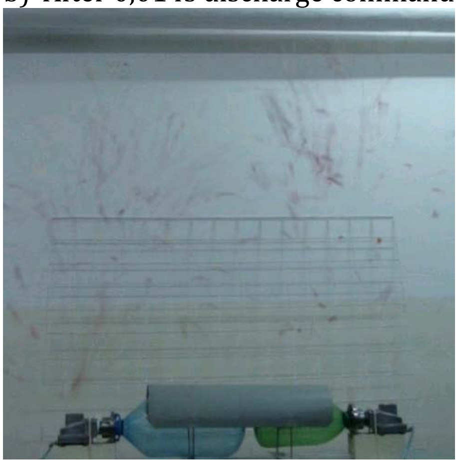
The second method proposed to determine the shock wave velocity using high speed camera Fastec Imaging type [8].

To determine the shock wave velocity (initial pressure p_o = 3…10 bar), paper pieces contrast colored were introduced into *FPV*'s convergent nozzle (Figure 12). A white panel with 0,1×0,1m horizontal and vertical grids was used.



a) After 0,009s discharge command

b) After 0,014s discharge command



c) After 0,017s discharge command

Figure 12. Shock wave velocity evolution by using high speed camera

According the shock wave velocity value', the image capturing sequence was set for 250 frames per second, and 320x240 sensor resolution. The high speed camera MiDAS 4.0 Express Control Software start was simultan triggered with *FPV* [7].

The values for shock wave velocity obtained by using high speed camera are 5…10% smaller then those obtained in the previous presented method.

In the previous method, the conical nozzle concentrates the shock wave to the large base, into a high velocity laminar flow.

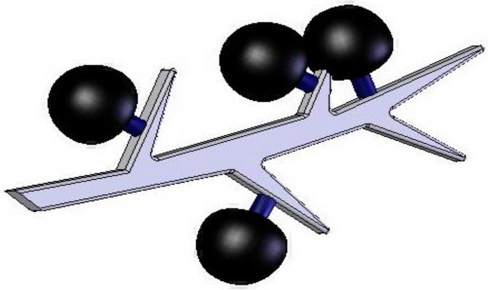
In high speed camera method, in the front and at the border of the shock wave, due to viscosity force, the turbulent flow determines the decrease of shock wave velocity.

A theoretical method that considers the viscosity effect and the shock wave effect is very difficult to approach.

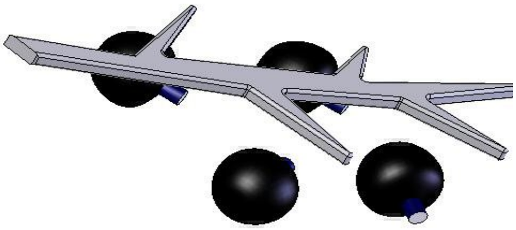
To optimize the nutty fruit harvest using pneumatically impulses, FEM simulation it was used. For FEM simulation it was necessary to determine the compressed air's shock wave velocity that takes into consideration all the simultaneous effects. FEM simulation of the shock wave influence to the tree branches, produced by one *PID,* had considered initial pressure p_o = 3 – 5bar [2, 4].

The *PID* were positioned at 0,7 - 1,2m to the tree branches, the jet range x_{lim} = 1,1 - 2,3m and jet diameter $D_{g\,r}$=1,4 - 2,4m.

In figure 13 is presented FEM simulation of 5bar shock wave effect after 0,1s (a), and 0,4s (b), respectively, toward 4 nut type fruits placed on an elastic branch; the distance between the *PID* position and tree branch was x_{lim} = 1,3m and the shock wave diameter was D_{gr} = 2m.



a) Shock wave effect after 0,1s actuation



b) Shock wave effect after 0,4s actuation

Figure 13. FEM simulation shock wave effect obtained with 5bar initial pressure

5. CONCLUSION

Air shock wave velocity obtained by using experimental equipment for nuts harvesting can be determined both with theoretical method, and experimental methods, too. Due to air fast discharge, there are many variable parameter could determine just aproximative velocity values. Due to their high accuracy, Vishay pressure and velocity traducers offer the precise values, only in the shock wave center, with no indicative values for the conical angle and dimensions of the shock wave border. High speed camera method accuracy is comparable with results obtained by using Vishay traducers, and in the same time permit to determine all the shock wave parameter to optimize the nuts harvesting experimental equipment.

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