The 3rd International Conference on ″Computational Mechanics and Virtual Engineering″
COMEC 2009
29 – 30 OCTOBER 2009, Brasov, Romania

SHOCK WAVE VELOCITY ANALYZE OF MODULAR EQUIPMENT FOR NUTS TREES SHAKE-HARVESTING

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Abstract: *The paper presents an unconventional high velocity process representing a new nutty fruits harvesting method. The general description of modular equipment using pneumatic impulses which realizes shock wave equivalent with a wind blast up to 90 km/h velocity is also presented. 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.*
Key words: *nuts trees, harvesting, shock wave velocity*

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, the harvest is made manually in principle, 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.
The mechanized harvest, necessary in large plantations, needs special machines and devices that are very expensive. The mechanized harvest demands to be used hydraulic or mechanical vibrators mounted on tractor. To prevent the tree trunk scratching, these machines are provided with an articulated shaft with rubber protection system. Before the natural falling, the harvest made with the vibrator is used with an auto mechanized machine to gather all nuts fallen on the ground. Such harvesting system is economically efficient only in 40 ÷ 60 ha nuts or hazelnuts plantation. [5]
An important role in the nuts harvest is held by the intensity of wind's action, which determines fruits dropping.

2. MODULAR EQUIPMENT FOR NUTTY FRUITS HARVEST BY PNEUMATIC IMPULSES

An unconventional technology was proposed to replace windblasts effect with directioned pneumatically impulses with adjustable intensity simulating the velocity and orientation of strong winds.
Modular equipment for nuts harvest by pneumatic impulses (figure 1) was made in the Unconventional Technologies and Equipment for Agricultural - Food Industry Laboratory, within the Faculty of Horticulture in Craiova. [5]

Figure 1: Modular equipment for nuts harvest by pneumatic impulses

The modular equipment for nuts harvest by pneumatic impulses experimental (*MENPI*) is mounted on a rigid metallic support placed on the front side of a tractor U650M, which offers to the operator to correct the tractor's position to the trees that must be harvested. [5]
The *MENPI*'s main operational component is composed in 4 pneumatic impulses device (*PID*), whose relative position to the tree's branches can be modified. In principle, each *PID* (figure 2) consists in 8dm^3 capacity vessel with a special fast pneumatic valve due to the compressed air (initially stocked in the vessel) is discharged with sonic/supersonic velocity. The *PID* operation needs 3…10bar compressed air supply source (up to 10bar tractor's compressor or supplementary motor-compressor). [5]

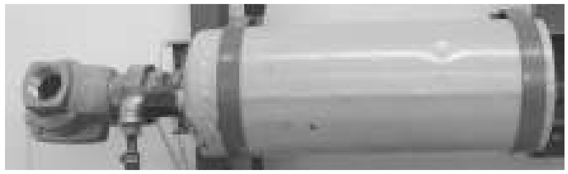
Figure 2: Pneumatic impulses device

3. THEORETICAL CONSIDERATIONS CONCERNING SHOCK WAVE VELOCITY

Technical equipment *PID* operating, 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. 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:

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

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). [2, 3, 4]
In slow / static adiabatic transformations, which are isentropic (the entropy S is constant).
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).
When the compressed gas is discharged from a storing vessel (initial parameter p_o, ρ_o, T_o) through a nozzle in the atmosphere (characterized by parameter p_{at}, ρ_{at}, T_{at}), the gas velocity is determined with relation:

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

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:

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

where cross section area of the convergent nozzle/pipe (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.

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

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} confirm the impulsive phenomenon ($t_{disc} = 0,0265$ s).
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 3).
This free jet is a gas current that freely penetrates (with small friction forces restriction) into an environment of the same or different gas (the flow in jet is generally turbulent, particles of the discharged gas getting out its limits, with neigh-boring gas particles taking their place; a mass gas transfer with the exterior is achieved). 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. [2, 3]

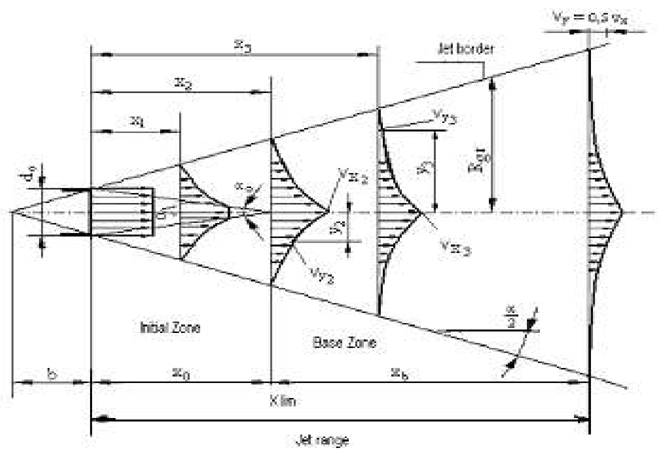

Figure 3: Circular jet geometry

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_e can be equal to zero, bigger or smaller than v_o and for $v_e = 0$, 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 $v_x = v_o$, 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

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

where R_{gr} is the jet's radius limit for $x > x_o$.
Due to the symmetric axial jet law, the impulse has the same value in any section. Using the notation $\boldsymbol{v_y}$ 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:

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

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

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

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:

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

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

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

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 $60 \div 200$ km/h); jets range $x_{lim} = 0,7 \div 2$m; enlarging jet border angle $\alpha = 53^o \div 67^o$. [2, 3, 5]

4. EXPERIMENTAL CONSIDERATIONS CONCERNING 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 (figure 4).
For FEM simulation it was necessary to determine the compressed air's shock wave velocity that takes into consideration all the simultaneous effects. [1, 4]

Figure 4: FEM simulation of shock wave influence to the tree branches using one *PID*

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 (dimensions 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 circular nozzle of the *PID* electropneumatical fast discharge valve [7, 9]. The discharging time (the period between the initial trigger's time of the electropneumatical fast discharge valve, and the moment when the discharged pressure is maximum) was measured.
In figure 5 and 6 are presented the dynamic pressure evolutions and the discharging time (shock wave duration) obtained for an initial pressure p_o = 5 bar, and p_o = 7 bar, respectively.

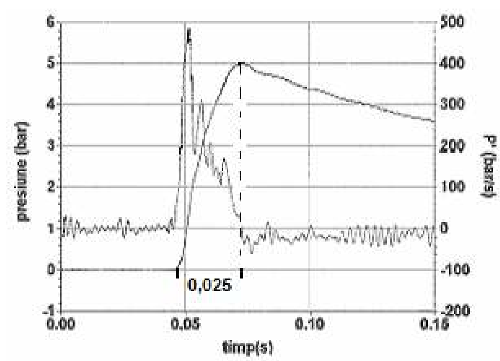

Figure 5: Discharging time for an initial pressure p_o = 5 bar

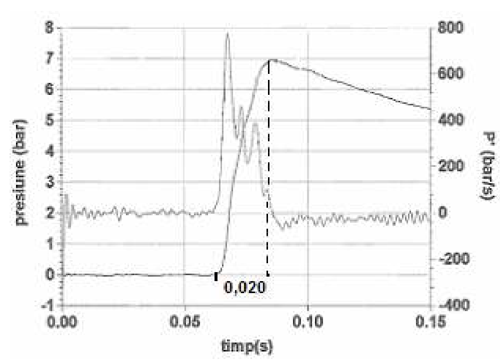

Figure 6: Discharging time for an initial pressure p_o = 7 bar

The discharging time t_{dish} and the shock wave velocity v_{sw} and equivalent wind velocity $v_{eq\text{-}w}$ obtained for initial pressure p_o = 3…10 bar are presented in table 2 (comparable with the theoretical value t_{disc} = 0,0265 s).

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), a fine powder contrast colored was introduced into convergent nozzle of *PID*'s electropneumatical fast discharge valve (figure 7). A white panel with 0,5m horizontal and vertical grids was used.
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 simultaneous triggered with the *PID*'s electropneumatical fast discharge valve. [8]
The values for shock wave velocity determined with this innovative method are 3…6% 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.

Figure 7: Shock wave velocity using high speed camera

5. CONCLUSION

To determine the shock wave velocity of modular equipment for nuts trees shake-harvesting were used two methods. The shock wave velocities in atmospheric open process are possible to be determined using high speed camera with specialized software. The high speed camera method needs to be compared with results obtained using traditional methods.

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