Considerations concerning impulsive air shock waves utilization in small and middle farms activities

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Abstract: The paper presents recent experimental design and process optimisation for impulsive air shock waves equipments that can be used for nutty fruits harvest, and bulk grain aeration in small and middle farms, respectively. There are described products development proposed to be included within the innovation and regional sustainable development strategically program.

Key-Words: portable equipment for nuts harvest, modular equipment for bulk grains aeration

1 Introduction

To prevent any problem in bulk materials stored in bunker or silos, discharging equipment, technical and commercial well-known as Air Cannon (or Big Blaster, or AIRCHOC), many years ago were begun to be used in USA and west European countries.

The Air Cannons systems are pneumatic devices that quickly release compressed air into a storage bunker for bulk material moving, or to restore the material’s flow that is clinging, rat-holing, bridging or arching [13-15].

In principle, the Air Cannon device is composed in a pressured gas vessel with a special pneumatic fast valve; due to this special pneumatic fast valve, the compressed gas that is initial stocked into the vessel, is quickly discharged in sonic velocity range.

Air Cannon devices have to be mounted on the metallic or concrete storage bunker [13-15].

In Romania there are known several technical applications for solid and powder bulk materials in large electrothermic plants (Fig. 1), cement plants, raw materials for metallurgy, dust filtering system for belt conveyors (Fig. 2), and for viscous materials in food industries (Fig. 3) [14].

It must be mentioned that some of these Air Cannons applications were exported in China - for a large electro power plant, in Iran and in Philippines - for large cement plants (Fig. 4) [14].

In USA and west European countries the Air Cannons systems are recommended to be used for bulk grain mechanical mixing aeration into very large capacity silos in large farms [13,15].

In order to optimize the compressed air consume, to decrease the initial investment costs and maintenance, and to decrease the dynamic loads in the walls of the bunker, there were made small and large capacity air blaster devices with two opposite pneumatic fast valve [14].

The metallic bunkers for coal storing in large electro-thermal plants or for row materials in cement plants consist in complex structure with large dimensions that determine large storage capacity (2000…2500m³ volume for each bunker).

![Fig. 1. Air Cannon devices (150 liters capacity) mounted on the metallic walls of large bunker for coal storing in large electro-thermal plant](image1)

![Fig. 2. Small capacity Air Cannon (12 liters capacity) mounted on the wall of coal dust filtration system for belt conveyor in large electro-thermal plant](image2)
The bunk shape, and the physical - mechanical characteristics of the bulk materials stored into the bunker, too, could cause often bunker blockage.

The static pressure of the weight of the stored bulk material, and the high rate of the impulsive kinetically energy produced by the Air Cannons during the short time there are actuated, could determine hazardous damages on the bunker structure. This is the reason for there were necessary theoretical (classical strength materials, dynamic plasticity, thin plates and shells theory, and FEM, too) and experimental interdisciplinary researches concerning the effect of impulsive kinetically energy of the air shock waves on metallic bunker stability [1-3, 6, 7, 10].

The theoretical and experimental experience proved in industrial results applications by using Air Cannons systems for solving technical problems caused by bulk materials blockage was extended for nutty fruit harvest.

The nuts (both the fruit and the pericarp) gradually reach maturity and fall, but the fall of the nuts is accelerated by rain, cool nights and wind.

In large plantations is used the mechanized harvesting method which requires special machines and very expensive devices consisting of hydraulic or mechanical shaking vibrators.

Multi Purpose Orchard Shaker Power Plant is well - known for large orchards fruits harvest. For middle size orchards cider fruits, for small rows upper 4m, Hydraulic Trunk Shakers are recommended.

During harvesting with these specialized 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 [4,5].

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

Ecological equipment Modular Equipment for Nuts Harvesting by Pneumatic Impulses (MEHPI) was designed, realized and tested (Fig. 5).

The equipment prototype tests in large orchards demonstrated that this experimental equipment can replace the effect of strong winds blasts, with orientated air shock waves.

This equipment realizes nuts harvest only by branches impulsive shaking with no direct contact with the tree [4,5].

MEHPI is mounted on a rigid metallic support placed on the front side of a tractor U650M that permits the 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 [4,5].

In principle, each PID consists in 8dm³ metallic vessel with a special fast discharge pneumatic valve (FDPV) due to the compressed air (initially stocked in the vessel) is discharged in sonic velocity range.

The PID operation needs 3…7bar compressed air supply source (the tractor compressor) [4,5].
2 Problem formulation

2.1 Nutty fruits harvesting
In hilly and slow slope mountainous regions there are many small irregular nutty farms and small isolated orchard. In these kinds of regions the crop quality and productivity depend on frequent weather changes. The nuts gradually reach maturity, and for the best nuts quality (for chocolate industry, not for selling in free market places), an optimum short harvesting period must be respected.

Due to the irregular shape and slopes of the land that characterize these kinds of regions, specialised harvesting equipments or Modular Equipment for Nuts Harvesting by Pneumatic Impulses, too are not possible to be used.

Experimental design and process optimization were necessary to realize portable and modular equipment for nuts harvesting by using air shock waves that could be used in any small or middle farm.

2.2 Bulk grains dynamic aeration
In large agricultural farms, after the crops harvesting, the bulk grains are stored for long time in large cement silos (6000…8000m$^3$ volume capacity) provided with complex ventilation systems that must realize the grains aeration. During the long time storage the grains are periodically moved out the silo for intensive mechanical mixing realized by using traditional agricultural equipment and multiple belt conveyor mixing equipment.

Due to the intensive impact and friction phenomena between grain particles during mechanical mixing, the sensible life stage of insects (eggs, larva) are almost killed or inactivated. In the same time, during the mechanical mixing, the bulk grains are very short time natural ventilated.

The traditional method for bulk grain ventilation stored into large silos in large farms is based on artificial ventilation, but no mechanical mixing aeration is possible.

In small and middle agricultural farms, after the crops harvesting, the bulk grains are stored for several months in metallic or wooden silos (30…80m$^3$ volume capacity), with no sealing system.

Therefore no ventilation system can be operated in such conditions, with no possibility for bulk grains aeration.

An new method was proposed to replace the ventilation effect during grains storage with the dynamic aeration realized by using the impulsive air shock waves energy. Experimental design and process optimization were necessary to make a portable air shock waves equipment that could be used for bulk grains aeration in any small or middle farm.

3 Experimental design and process optimization

Experimental design and process optimization for nuts harvesting equipment

For nuts small farms and isolated orchards, Portable modular equipment for nuts harvesting (PEHPI) was experimentally design (Fig. 6). 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 very small and irregular orchards, PEHPI’s mobility is realized due to two wheels. For small and middle irregular nuts farms, the metallic frame can be mounted on 9-15HP 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 (PWG) realizes impulsive air shock wave that replaces high velocity wind blast effect. PWG is composed in: pressured gas supplying device; modular compressed gas command circuit; two special PID.

In Fig. 6 is presented PEHPI with a compressed gas source consisting in independent CO$_2$ pressured vessel (pressure reducing device realizes low pressure stage up to 5 bar). It must be noticed that during the equipment testing, due to CO$_2$ detention, the reducing device has frozen. Thus, pressured CO$_2$ supplying device has to be utilized with special precautions.

Therefore, for PEHPI safety operation, the recommended pressured gas supply devices are 12CP motocultivator, small tractor end power shaft, or 6 bar independent motocompressor. PEHPI’s operational component is composed in two new designed PID, consisting in small capacity vessel, and a special FDPV (Fig. 7).

To increase PEHPI’s manoeuvrability during harvest operations, PEHPI needs lighter weighting of the compressed gas vessel. There are well-known the mineral water bottles made in PET.

An innovative idea was used to recover and to recycle any type of mineral water bottles, to be used as compressed gas storage vessel for this experimental equipment PID. 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 could resist up to 9bar, and more than 250 cycles of compressed air filling.

To optimize the harvest process and to avoid dangerous dynamic bending that could determine the tree’s branches damaging, the velocity of impulsive shock waves have to be precisely determined and controlled.

3.1.1. Theoretical considerations concerning impulsive shock wave velocity

When the compressed gas is discharged from a storing vessel (initial parameter $p_o, \rho_o, T_o$) through a nozzle in the atmosphere (final parameter $p_{at}, \rho_{at}, T_{at}$), the gas velocity is determined with relation [5]

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

Because the ratio $(p_{at}/p_o)$<0.5283, in the minimum cross section of the convergent nozzle the critical regime is realized. The maximum flow that is obtained (when passing through this cross section) $Q_{max}$ can be determined with relation [5,8]:

$$ Q_{max} = 0.04042 \cdot S_p \cdot \rho_o / \sqrt{p_o} \quad (2) $$

where $S_p$ is cross section area of the convergent nozzle (in this paper the convergent nozzle $D_p \approx 44$mm).

Considering the initial and the final parameters of the gas ($p_o = 3\ldots10$ bar; $p_{at} = 1$ bar; $T_o = T_{at} = 293^\circ K$; $k = 1.4$), the velocity of the pressured air $v$ discharged from the storing vessel, and the maximum flow $Q_{max}$ passing through cross section $S_p$ are given in Table 1. Knowing the compressed air mass in the storage vessel ($C_v$ - vessel capacity) is $m_{vo} = C_v \rho_o$, using the $Q_{max}$ values in table 1, the vessel’s discharging time values are $t_{disc} = 0.020\ldots0.0255$s. These values confirm the SMC type fast discharge pneumatic valve characteristics [5,8,12].

### Table 1. Velocity and maximum flow of the discharged air

<table>
<thead>
<tr>
<th>$p_o$ [bar]</th>
<th>$\rho_o$ [kg/m$^3$]</th>
<th>$v$ [m/s]</th>
<th>$Q_{max}$ [kg/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3.57</td>
<td>398.1</td>
<td>1.077</td>
</tr>
<tr>
<td>4</td>
<td>4.76</td>
<td>438.5</td>
<td>1.435</td>
</tr>
<tr>
<td>5</td>
<td>5.95</td>
<td>465.7</td>
<td>1.795</td>
</tr>
<tr>
<td>6</td>
<td>7.14</td>
<td>485.5</td>
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</tr>
<tr>
<td>7</td>
<td>8.33</td>
<td>500.9</td>
<td>2.512</td>
</tr>
<tr>
<td>8</td>
<td>9.52</td>
<td>511.8</td>
<td>2.871</td>
</tr>
<tr>
<td>9</td>
<td>10.71</td>
<td>523.6</td>
<td>3.230</td>
</tr>
<tr>
<td>10</td>
<td>11.89</td>
<td>532.7</td>
<td>3.590</td>
</tr>
</tbody>
</table>

The theoretical considerations concerning the gas discharge from the stocking vessel take into account the similitude with the flow process into round free jet. Characteristic dimensions of the convergent - divergent nozzle determine the main dimensional parameters of the impulsive round free jet that shakes the tree’s branches: $R_{jb}$ - jet border radius; $x_{lim}$ - jets range lengths; $\alpha$ - jet border angle.

The average velocity of jet $v_m$ is determined knowing that the medium flowing velocity in any transversal section is obtaining from the continuity equation [5,8]:

$$ v_m = Q / (\pi R_{jb}^2) \quad (3) $$

where $R_{jb}$ is the jet border radius.

Using this relation (that take into consideration no gas viscosity effect and no shock wave effect), for initial compressed air pressure in the storage vessel $p_o = 3\ldots10$bar, were obtained theoretical results for: average velocity in the jet section $16.6\ldots55.5$m/s; jet border angle $53^\circ\ldots67^\circ$; jets range lengths $x_{lim} = 0.7\ldots2$m. [5,8]

3.1.2. Experimental considerations concerning impulsive shock wave velocity

To determine the impulsive shock wave velocity high speed camera Fastec Imaging type was used [11].

To determine the shock wave velocity (initial pressure $p_o = 3 - 10$ bar), contrast coloured plastic pieces were introduced into $FDPV$’s nozzle and $0.1 \times 0.1$m grids panel was used. (Fig. 7).
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 FDPV [11].

The values for shock wave velocity obtained by using high speed camera are 7…12% smaller then those obtained by theoretical considerations, that considers shock wave 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.

![Image](image1.png)

a) After 0,010s discharging command

![Image](image2.png)

b) After 0,015 s discharging command

![Image](image3.png)

c) After 0,020s discharging command

Fig. 7. Impulsive shock wave velocity evolution

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**3.2. Experimental design and process optimization for bulk grains aeration equipment**

For bulk grains mixing and aeration in small or middle farm the experimental equipment was made consists in 8 dm³ PID.

The intensive grains mixing process and the simultaneous aeration process of the bulk grains stored into metallic or wooden silos in small farm are impossible to be visual observed, but only the impulsive shock wave effect can be finally evaluated.

Taking into account only visual demonstrative experimental considerations, this paper presents a silo’s walls made in high grade shock resistance transparent glass (Fig. 8).

**3.2.1. Theoretical considerations concerning impulsive shock wave velocity and energy**

The average velocity of shock wave \(v_{med}\) was theoretical determined considering that the medium velocity in a flow section can be determined with relation \(v_{med} = 0.2 \cdot v_{max}\). Assuming fast and complete discharge of the all pressured gas weight initial contained into 8 dm³ capacity storage vessel, the kinetically dynamic energy \(E_{K,dyn}\) determined with well known relation \(E_{K,dyn} = (W_{sv} \cdot v_{med}) / 2\), is presented in Table 2. The aim of this paper is to realize the bulk grain aeration, and bulk grain moving, too. Thus, the kinetically dynamic energy \(E_{K,dyn}\) must be greater then the potential energy \(E_{pot}\) of the bulk grain column weight \(W_{bg}\) that exist above the PID discharge pipe axis \((E_{pot} = W_{bg} \times g \times H)\).[9]

<table>
<thead>
<tr>
<th>(p_o) [bar]</th>
<th>(v_{med}) [m/s]</th>
<th>(W_{sv} \times 10^{-3}) [kg]</th>
<th>(E_{K,dyn}) [J]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>68,1</td>
<td>22,72</td>
<td>43,81</td>
</tr>
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<td>73,2</td>
<td>27,36</td>
<td>62,14</td>
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<td>81,5</td>
<td>36,48</td>
<td>104,8</td>
</tr>
<tr>
<td>5</td>
<td>87,4</td>
<td>43,36</td>
<td>146,48</td>
</tr>
</tbody>
</table>

**3.2.2. Experimental considerations concerning impulsive shock wave velocity and energy**

According the shock wave theoretical velocity values, the high speed camera image capturing sequence was set for 500 fps. The high speed camera MiDAS Software start was simultaneous triggered with the PID’s fast discharge pneumatically valve.[11]

In order to increase the visibility during experimental efficiency tests, the transparent silo was filled with bulk grains. The PID was activated for consecutive pressures (2, 3, 4, 5 bar). In Fig. 8 are presented the first six frames during 0,107s total timing of the bulk grains mixing and aeration process.
During these experiments it was observed that the shock wave kinetically dynamic energy realize the bulk grains mixing, and in the same time, the aeration, too.

4 CONCLUSIONS

Experimental design were necessary to made modular and portable equipment that contribute for the process optimization for nuts harvesting by using air shock waves, and for the bulk grains mixing and aeration by using air shock waves that could be used in any small or middle farm.

These products development are proposed to be included within the innovation and regional sustainable development strategically program.

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