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SONIC GENERATOR DRIVEN BY WIND VIBRATING MECHANISM

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Abstract: The study of the dynamics of wind turbines deals, among other aspects, on the harmful effects of vibration either on the fatigue of materials, the rotor aeroelastic instability, noise or other vibrational phenomena. However, oscillatory movements can be beneficial for the processing and transport of mechanical energy. Indeed, an aeraulic mechanism working in special conditions (for example, by self-vibration or resonance) can be used to extract the wind energy. Afterwards, this mechanical energy can be communicated to a sonic generator through a resonant line. This arrangement can be seen as a new type of wind turbine that is fundamentally different from the vertical axis wind turbine (VAWT) or the horizontal axis wind turbine (HAWT) called vibrant wind engine (VWE).The theory of VWE will be discussed and few vibrant mechanisms will be presented and commented.
Keywords: Sonics, Vibrant wind machine, Resonance, Self-vibration, Sonic network

1. INTRODUCTION: CLASSES OF COMPONENTS OF A WIND TURBINE

A wind turbine is made to extract mechanical energy from the wind and turn it into other forms of energy suited to the various applications such as mechanical energy (rotational, translation or roto-translation), electric power, thermal energy, etc. Figure 1 shows the main component classes of a generic wind turbine where: S, the energy source (wind), E, the extractor of wind energy, T, transmission and transformer of energy, M, modulators of energy and C, the consumers (electric networks, isolated users, etc.).

The wind turbine is a turbine powered by $\mathbf{S}$, a current of air, generally, the natural wind. Unlike hydraulic turbomachinery who are driven by a jet of fluid through a pipe under almost constant pressure (because of the extent of the accumulation lakes), the wind turbine uses a drowned jet whose characteristics are generally random. This has implications for construction, control and operation of a wind turbine, consequences which are absent in the case of hydraulic generators. Indeed, the use of confined liquid jet allows the command of the input power by manipulation of simple valves, which modulate the admission of the liquid to the turbine blades. Thus, the predictability and ease of modulation of the input flow allow the realization of a stable movement of the rotor of the generator and so it ensures an electric wave of quality. On the other hand, the wind being not harnessed, the wind turbines have to deal with an input power variation between approximately known limits by statistical measures of a site over large periods of time (Ilinca A., McCarthy, E., Chaumel J., Retiveau J., 2003).

The system $\mathbf{E}$ has a multitude of possibilities to make the capture (Spera D. A, 1994, Hau E., 2006, Saulnier B., Reid A., 2009, Olives, Hedgehog A., Binda C., Thierry J., 2013). However, currently on the market are mainly two solutions: wind turbine with horizontal axis (HAWT) and, in a smaller segment of market, the wind turbine with vertical axis (VAWT) (Paraschivoiu I., 2002, Patel, M., R., 2006). This trend is due to the ability of the turbine to extract energy from the wind. Indeed, from this point of view, the horizontal axis turbine with 3 blades presents the greatest performance, with a power factor $c_p = 45\%$, not far of Betz index ($c_p = 59\%$), while the wind turbine vertical axis with c_p= 30% is next (Patel M., R. 2006). However, HAWT must be fitted with the devices orientation against the wind on the difference of VAWT which is omnidirectional (Martel P., Dery J. 2005). Just by looking quickly at these two types of wind turbines, we deduce that the capture of the energy is based on specific body: the blade.

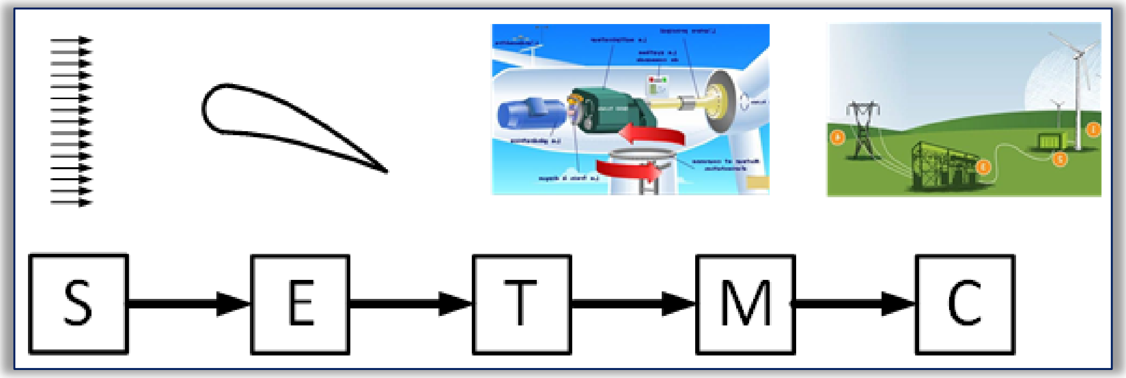

Figure1 – Classes of components of a wind turbine

Transmission T is the subsystem that is most diversified. It may have the form of a simple shaft or up to a quite sophisticated mechanism with multiple degrees of mobility. This part also includes the various generators and transformers of energy: mechanic, hydraulic, electric, pneumatic, sonic, etc.
Modulators M regulate and direct the flow of energy: adjustment of the voltage, intensity or the phase of the current (electric or sonic), the distribution of the fluid, clutch, declutch, braking of the shafts, etc. Also note that to ensure the stability of the wave (electrical, sonic, or other) should be used mechanical or electrical devices that can be costly, bulky, inefficient, energy consumer, difficult to operate, etc. (Labonville R., 2008).
Finally, consumers C absorb the energy provided by the chain, and turn it in other energy or mechanical work.
Researchers, inventors, companies and hobbyists have invested many efforts in this area on several directions, as for example:
— the conditioning of air stream by capture and duct (Allaei D., Andreopoulos Y. 2014, Grant A., Kelly N., 2004);
— the introduction of new systems to capture the movement of the wind (Festo, 2014, Stinson E., 2015);
— the invention of some systems of transformation of mechanical energy into other forms of energy (Patel M., R., 2006).
The conditioning of the air is necessary since wind is a field of low energy density in comparison, for example, to a liquid medium. The idea is to harness the current with a static device, and directs it through a tapering passageway that passively and naturally accelerates its flow.
In the following lines, we will get mainly of a new extraction system of wind energy as well as with the transformation of this energy into vibrational energy.

2. MATERIAL AND METHOD

— The theory of self-vibrations produced by fluid flow around à body

Be an airfoil whose chord is tilted at an angle α from the horizontal and who is under the influence of a horizontal airflow of speed $\bar{v}$ (figure 2 a). The resultant of the forces of pressure applied on the profile has two components which can be determined, by testing in a wind tunnel, and who present themselves as curves given by the functions (Den Hartog J. P., 1934, Voinea R., Voiculescu D., Simion Fl. P., 1989, Paraschivoiu I., 2002) :

$$P = P(\alpha) \quad T = T(\alpha)$$

These forces are called the lift, P, respectively the drag, T and act as forces applied to the profile (Paraschivoiu I., 2002, Patel M., R., 2006, Spera D. A., 1994).

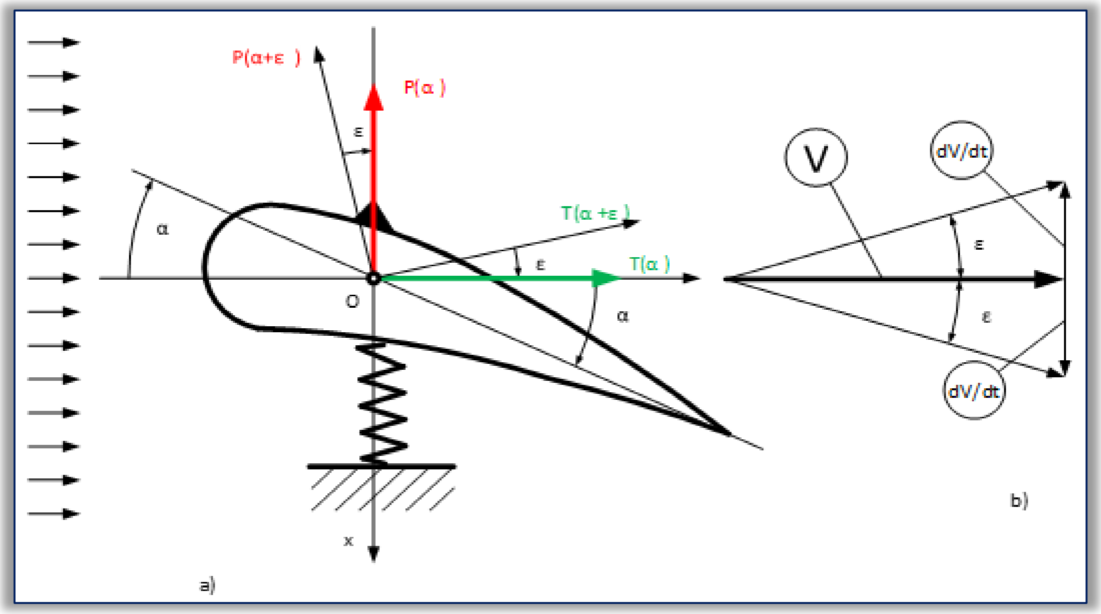

Figure 2 – Self-vibrations induced by fluid flowing around a body

We study the motion of the profile on the vertical direction, denoted with x, and considered to be positive downward. If at some moment, the airfoil is under the action of an elastic force kx, the equation of motion is of the form,

$$-kx - F = m \cdot \ddot{x} \quad (1)$$

The force F is equal to the projection, on the axis Ox, of the resultant of the forces of drag and lift.
If the profile is at rest, this resultant is given only by the lift force $\mathrm{P}(\alpha)$ but, if the profile is moving in the positive direction of the vertical axis Ox with a speed $\dot{x} \ll v$ then, the relative speed of the air regarding the airfoil, makes an angle ε (figure 2b) given by the relationships,

$$\tan\varepsilon = \frac{\dot{x}}{v} \approx \sin\varepsilon = \varepsilon \approx \frac{\dot{x}}{v} \quad \text{et} \quad \cos\varepsilon \approx 1$$

Under these conditions, the drag and lift have the expressions:

$$P = P(\alpha+\varepsilon) \quad T = T(\alpha+\varepsilon)$$

and the projections of these forces on the axis Ox will be the force $-F$ where,

$$F = P(\alpha+\varepsilon) \cdot \cos\varepsilon + T(\alpha+\varepsilon)\cdot \sin\epsilon = P(\alpha+\varepsilon) + T(\alpha+\varepsilon)\cdot\varepsilon$$

Since ε is small, we can develop in Taylor series and retain only the linear terms, and with

$$P(\alpha+\varepsilon) = P(\alpha) + \frac{\partial P(\alpha)}{\partial\alpha}\varepsilon \;\text{ et }\; T(\alpha+\varepsilon) = T(\alpha) + \frac{\partial T(\alpha)}{\partial\alpha}\varepsilon$$

we get

$$F = P(\alpha+\varepsilon) + T(\alpha+\varepsilon)\cdot\varepsilon = P(\alpha) + \frac{\partial P(\alpha)}{\partial\alpha}\varepsilon + \left[T(\alpha) + \frac{\partial T(\alpha)}{\partial\alpha}\varepsilon\right]\varepsilon$$

Neglecting the terms in ε^2 finally, there are the expression of the aerodynamic force acting on the direction $-Ox$,

$$F = P(\alpha) + \left[T(\alpha) + \frac{\partial P(\alpha)}{\partial\alpha}\right]\varepsilon$$

Then the movement equation (1) becomes,

$$-kx - P(\alpha) + \left[T(\alpha) + \frac{\partial P(\alpha)}{\partial\alpha}\right]\cdot\frac{\dot{x}}{v} = m\cdot\ddot{x}$$

or in a canonical form,

$$\ddot{x} - \frac{\left[T(\alpha)+\frac{\partial P(\alpha)}{\partial\alpha}\right]}{mv}\cdot\dot{x} + \frac{k}{m}x = -\frac{P(\alpha)}{m} \quad (2)$$

It recognizes here the equation that describes a damped vibratory movement,

$$\ddot{x} + \frac{c}{m}\cdot\dot{x} + \frac{k}{m}\cdot x = F$$

with the damping factor $c = -\frac{\left[T(\alpha)+\frac{\partial P(\alpha)}{\partial\alpha}\right]}{v}$.

Based on the damping factor the movement can be classified in :
- damped vibration, if $T(\alpha) + \frac{\partial P(\alpha)}{\partial\alpha} < 0$;
- harmonic vibration, if $T(\alpha) + \frac{\partial P(\alpha)}{\partial\alpha} = 0$;
- self-vibration, if $T(\alpha) + \frac{\partial P(\alpha)}{\partial\alpha} > 0$.

Since the drag $T(\alpha)$ is always positive, we see that the motion can be unstable if, on a portion of the curve, $P = P(\alpha)$, we have $T(\alpha) + \frac{\partial P(\alpha)}{\partial\alpha} > 0$.

The solution of the equation in the case of the self-vibrations is

$$x = A\cdot e^{\frac{\left[T(\alpha)+\frac{\partial P(\alpha)}{\partial\alpha}\right]}{2mv}\cdot t}\cdot\cos[\sqrt{\left(\frac{k}{m}\right)^2 - \left(\frac{\left[T(\alpha)+\frac{\partial P(\alpha)}{\partial\alpha}\right]}{2mv}\right)^2})\cdot t - \varphi] \quad (3)$$

Energetically, multiplying the equation (2) by $m\dot{x}$ we obtain,

$$m\ddot{x}\dot{x} - \frac{\left[T(\alpha)+\frac{\partial P(\alpha)}{\partial\alpha}\right]}{v}\cdot\dot{x}^2 + kx\dot{x} = -P(\alpha)\dot{x} \Leftrightarrow \frac{d}{dt}\left(\frac{m\dot{x}^2}{2} + \frac{kx^2}{2}\right) = \frac{\left[T(\alpha)+\frac{\partial P(\alpha)}{\partial\alpha}\right]}{v}\cdot\dot{x}^2 - P(\alpha)\dot{x}$$

But, with $E = \frac{m\dot{x}^2}{2}$ and $U = \frac{kx^2}{2}$, respectively the kinetic and potential energies, we have

$$\frac{d}{dt}(E+U) = \frac{\left[T(\alpha)+\frac{\partial P(\alpha)}{\partial\alpha}\right]}{v}\cdot\dot{x}^2 - P(\alpha)\dot{x}$$

Because the right member of the equation can be positive, we conclude that the total energy of the system $(E+U)$ may be increasing with time, and, furthermore, this growth is exponential.

In conclusion, in this section, we see from the equation (3) that the amplitude grows exponentially with time (unlike the case of resonance where the increase is linear) which makes that the self-vibrations are a very effective mean of extraction of the energy from the wind.

This brings us to look at a way to take advantage of this phenomenon by using this installation as an extractor of energy instead of the rotating blade.

In the next paragraph, we will show some possible patterns of vibrant wind turbines.

— Ideas on exploitation: the vibrant wind engine (VWE)

The above considerations invite us to think that instead of capturing energy via circular continuous motion of a propeller (like in HAWT or VAWT), the aerodynamic effect of instability that produces self-vibrations can be exploited. This vibrant motion has been considered as the worst case by the engineers who actively tried to design their devices to be far from these domains of operation (and, is to say, for a good reason). But, what can be seen as a danger for some can be an opportunity for others.

In order to do this, several steps must be overcome, namely:

- to ensure a linear displacement of the aerodynamic profile;
- to find a mechanism that will allow to modify easily the profile inclination during the operation;
- to design a mechanism for the transformation of oscillatory motion in continuous rotary motion.

The very first idea to guarantee a linear displacement of the profile is to guide the motion with a translational joint. However, in practice this is a bad idea because the translational guide has severe inconveniences (clearings, premature wear, noise, etc.). Instead, we will be looking for a mechanism with rotational joints only (figures 3, 4, 5 shows some possibilities).

Thus, in the Figure 3, the linkage AC, pinned at A, provides a linear motion of the profile as long as the displacement is small compared to the length AC.

To modify the inclination of the aerodynamic profile we need to stop the movement of the blade.

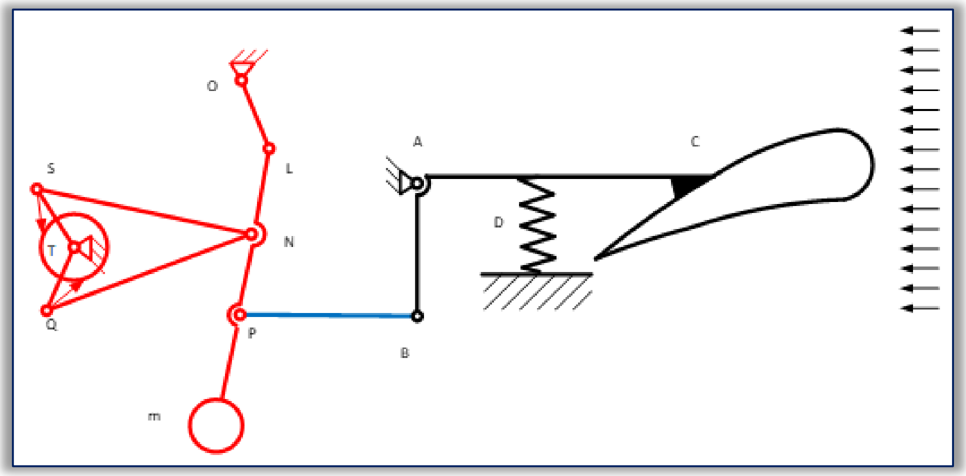

Figure3 – VWT with direct action on CCC

The Figure 4 shows a solution using a Sarrut mechanism (Cornellier C., 2017). The Sarrut mechanism, built of the linkages $\mathrm{AD}, \mathrm{CD}, \mathrm{KE}, \mathrm{FE}$ and AK, allows a translation vertical motion on AK platform, although all the elements moves rotationally.

To modify the inclination of the aerodynamic profile, the stop of the motion of the blade is needed.

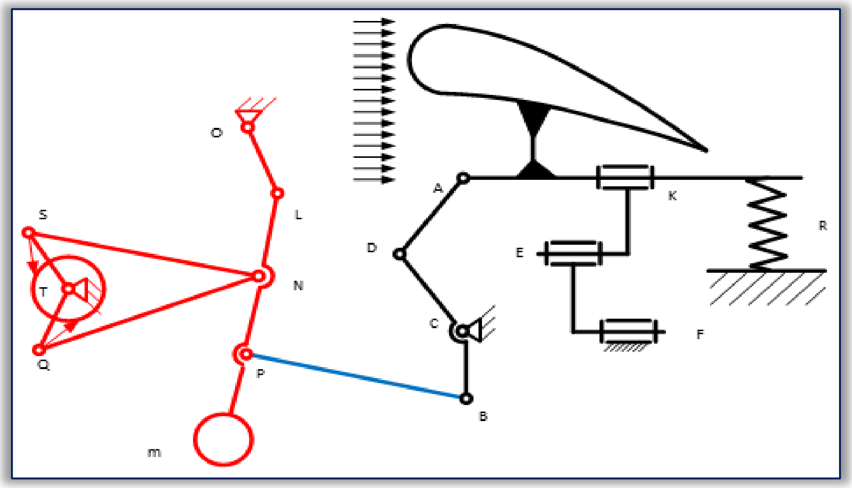

Figure4 – VWT with Sarrut mechanism action on CCC

Figure 5 exploits the properties of a Tchebytchev four-bar linkage AHDC, whose connecting rod is DG and the following relationships are true :

$$\mathrm{HA} = \mathrm{HD} = \mathrm{HG} = 2.5 \cdot \mathrm{CD}$$
$$\mathrm{AC} = 2 \cdot \mathrm{CD}$$

Under these conditions, the point G traces a straight line segment (Artobolevski I., 1975-1978). We builds on the segments GH and AH, the parallelograms GHEL, respectively, AHEB. We can easily see that the segment LG has a vertical displacement no matters what is the inclination of the fixed segment AB (which occasionally can be vertical). So, this segment can be used for the active displacement of the aerodynamic profile, glued at.

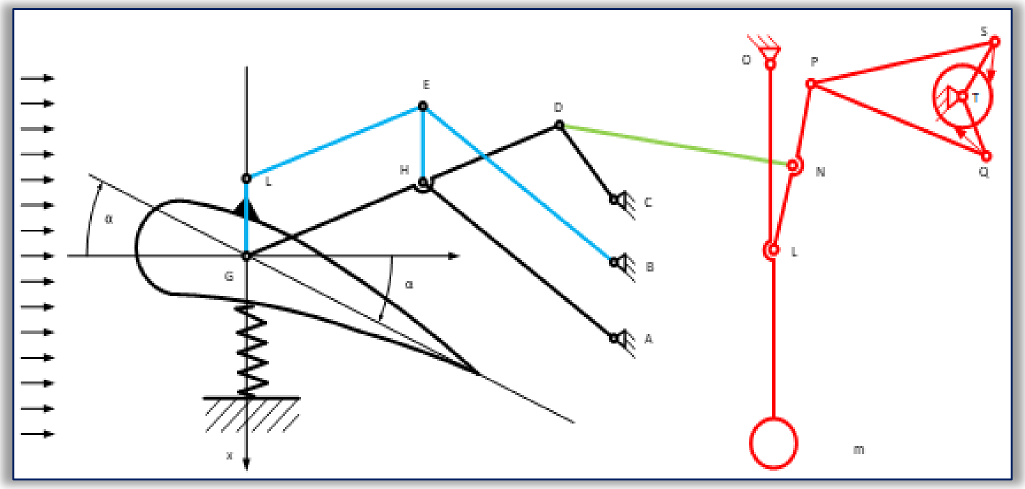

Figure 5 – VWT with Tchebytchev mechanism action on CCC

Moreover, by modifying the angle of AB, the angle α of the profile is automatically modified with the same value and this operation can be executed while the mechanism is still in motion.

Now, for the conversion of oscillatory motion of the body PB, on Figure 3 and 4, or link ND, on Figure 5, we have some feasible solutions.

For example, one can imagine the connected rod, attached to a piston of a sonic generator such that a sonic network will transport and transform the motion until the end of the transformation chain. That means than the wind engine is entirely vibrant (Constantinescu G., 1922, 1985, Abaitancei H., Pop I., Radu Gh. A., Pop Denes I., Vidican P., Radu S., 2010, Denes-Pop I., 2015, Mailloux M., 2017, Marcu I.-L., Ciupan C., 2016, Petric A. A., 2011, Pop I. I., 2006, Popescu G., 2016, Radu S. I., 2012).

Another possibility is to employ a Constantinescu's torque converter of two degree of mobility (the mechanism whose joints are $\mathrm{O}, \mathrm{L}, \mathrm{N}, \mathrm{S}, \mathrm{T}, \mathrm{Q}$) (Constantinescu G. 1985, Ene M., 2013, Mailloux M., 2017). The oscillatory motion in the point P excites this mechanism. The exit shaft T, can be rigidly connected with the rotor of a sonic generator thus, a sonic network will continue the rest of the transformations.

In this paper, we did not mention the issue of the omnidirectionality of the wing engine who is a common problem with HAWT and can be solved in the same way. Additionally, the INVELOX technology (Allaei D., Andreopoulos Y., 2014) or the concept of ducted wind turbine (Grant A., Kelly N., 2004) can be profitably integrated in the design of VWM.

Finally, a combination of sonic and electric systems can be necessary for some applications. This is a problem pertaining of the electricians and the solutions are numerous (Félice É., Révilla Ph., 2009, Husain I., 2003, Lautier Ph., Prévost M., Éthier P., Martel P., 2007).

3. CONCLUSIONS

This article is a contribution to the study of a vibrant wind device, a new concept of in the field of wind machinery. Our contribution are resumed in the following:

- the signalisation of the phenomenon of self-vibration and the possibility of application in the practice of the wind machinery, like an extractor of wind energy;
- the device of many mechanisms to be employed for wind harvest energy, like Sarrut mechanism, Tchebytchev mechanism, etc.;
- introducing a mechanism for the treatment of the movement, after his extraction, with the mean of Constantinescu's Torque Convertor;

The concept of VWM needs further theoretically investigations, laboratory experiments and prototype design in order to validate his viability.

Acknowledgement

This communication was stimulated by researches conducted by the professors of Engineering School of UQAT on the VAWT Dermond installed on the Experimental Center Donald Murphy of the University of Quebec in Abitibi Temiscamingue (UQAT) at Rouyn Noranda, Canada. UQAT Foundation has financially supported these researches for many years.

Note: This paper is based on the paper presented at ISB-INMA TEH' 2018 International Symposium (Agricultural and Mechanical Engineering), organized by Politehnica University of Bucharest – Faculty of Biotechnical Systems Engineering (ISB), National Institute of Research-Development for Machines and Installations Designed to Agriculture and Food Industry (INMA) Bucharest, The European Society of Agricultural Engineers (EurAgEng), Society of Agricultural Mechanical Engineers from Romania (SIMAR), National Research & Development Institute For Food Bioresources (IBA), University of Agronomic Sciences and Veterinary

Medicine Of Bucharest (UASVMB), Research-Development Institute for Plant Protection (ICDPP), Hydraulics and Pneumatics Research Institute (INOE 2000 IHP), National Institute for Research and Development in Environmental Protection (INCDPM), in Bucharest, ROMANIA, between 01–03 November, 2018.

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