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Scientific experimental research on plants stem vibro-cutting in dense environment

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A B S T R A C T

The article discusses the objective of testing the results of theoretical researches on cutting the water plants stem (cane) in the dense medium and in water medium in particular by means of empiric methods. A plant for cane vibro-cutting in the water environment has been developed, which enables to determine the cutting resistance force factors by means of resistance strain gage both in case of vibration and vibrationless cutting. Data obtained upon the results of the experiments from the theoretical research have been factually proved.

Keywords: Water plants, Vibro-cutting, Resistance forces, Energy consumption, Experimental results, Theoretical research.

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Introduction

The exploitation practice of different mowers/harvesters and the results of numerous research works [1-4] indicate that the segmental and rotary apparatus available for the plants stem cutting in the dense medium (water, soil) are not applicable. The segmental cutting apparatus aren't relevant for cleaning the reservoirs and channels from the water plants due to transmitters with complex structure and insufficient relief copy. They aren't applicable in the soil medium at all since the contacting surfaces get covered with soil, which inevitably leads to the breakdown and destruction of the machine parts.

The mentioned shortcomings are lacking in the rotary apparatus. Anyhow, their application in the dense environment is still related to other types of difficulties, which are caused due to the resistance forces of that very dense environment. The available cutting apparatus implement cutting of the plants stems without any support in usual conditions in case of 30÷50m/s circumferential velocity of the blade tip [2, 5].

Such a speed rate in the blades of the rotary apparatus generates forces in the dense environment, which exceed the stem cutting forces in several times. Due to those forces the rotation numbers of the rotor sharply fall down, as a result of which the overwhelming part of the stems is left uncut, the technological processes of harvesting is disrupted and the exploitative indices of the cutting apparatus deteriorate. In order to realize flawless cutting in the dense medium it is necessary to increase the rotation numbers in the rotor and therefore the consumed power.

The exploitation practice of the cutting apparatus and numerous research experiments testify that in order to implement proper cutting with the rotary cutting apparatus in the dense medium it is necessary to increase their power in 5÷6 times [1, 2, 4].

It is obvious that the wide-scale application of such cutting apparatus isn't economically viable; so upgrading of rotary cutting apparatus or the design of the new ones is an urgent issue.

The practice has shown that the first method is not prospective, since the attempts aimed at the improvement of the working process of the existing apparatus in the dense environment have doomed to failure [1, 5].

Thus, it is necessary to follow the second method, i.e. to develop a fundamentally new cutting machine.

The long-year experience gained from the activities implemented in the mentioned direction indicates, that the most efficient way of stem cutting in the dense medium is vibrational cutting in case when the blade performs vibrational movement with low amplitude (2÷8mm) and high frequency (50÷100 s^{-1}), while the rotor is provided with relatively small rotation numbers 0.1÷0.25s^{-1} [2, 3, 6].

The small rotation numbers and consequently the small circumferential (moving) speeds hardly cause any resistance forces in the dense environment, while the vibration movement of the blades rapidly reduces the cutting resistance forces in the stems [1, 2, 4].

As a result of investigations of the research works and analyses related to the mentioned issues we haven't managed to find one where the significance of the vibration cutting effect could be theoretically interpreted. That is why we have conducted some theoretical investigations with the aim of disclosing the main point of the mentioned phenomenon [6, 7].

During the theoretical research a calculation pattern has been selected, which enables to determine the resistance forces of the blade movement in the rotary cutting apparatus in water medium with great precision in case of blade vibration and without it. In the result of the theoretical investigations it has been proved that in case of vibration of the blade in the cutting apparatus, the resistance forces of the water medium decrease from 10 to 35 times [1, 7] depending on the rate of critical speed in the cutting process.

It is worth mentioning that due to the application of the selected original calculation scheme and the patterns of hydrodynamics it becomes possible to evaluate the phenomenon of resistance force reduction caused by the blade vibration in the water environment.

Materials and methods

It is obvious that the results of theoretical investigation can be accepted as a base only if they have been proved through the experiments. To this end we have developed and designed a laboratory plant, which enables to determine the dynamic parameters of the cane stem vibro-cutting in water medium.

The general layout and view of the mentioned laboratory plant are introduced in figures 1,2 respectively, while the working principle is as follows: the container filled with water, where the stems of the experimented plant, particularly those of canes are attached, rotates with the help of transmission shaft connected to the engine, while the rotary equipment consisting of the electromagnetic vibrator stays fixed/immobile. So, through rotation of the container the cane stems in the water medium is transferred to the vibration blade edge and their cutting is implemented.

The scientific experiments were conducted with two types of blades with toothed and flat edges. Besides, it has been proved through both theoretical [2, 4] and experimental methods, that the critical cutting force in case of the blade with toothed edge is much lower, than that of in case of the flat-edge blade.

Determination of some parameters in the process of vibration cutting will enable to conduct accurate analyses and to find optimal cutting regime for the stems. During vibro-cutting the oscillation amplitude (1÷5mm) and frequency (50÷100s^{-1}) of the vibro-blade, as well as the blade supplying speed (0.1÷0.5m/s) or the rotation number (0.1÷0.25s^{-1}) of the rotor are the most significant factors.

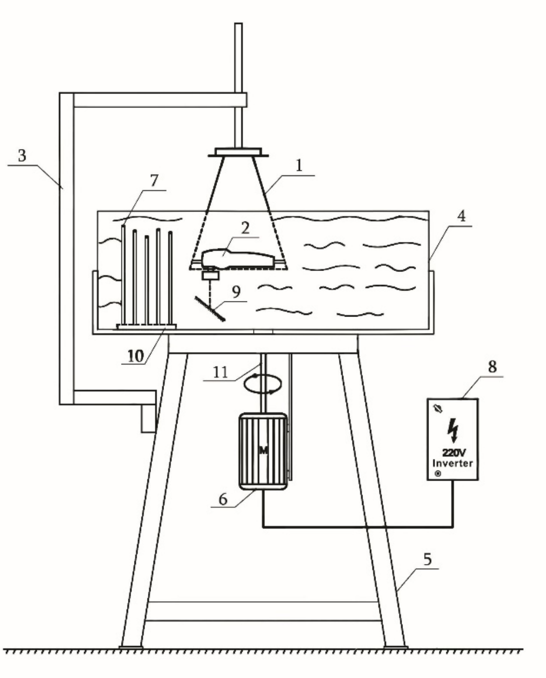

Fig. 1. *The general layout of the experimental plant for the stems vibration cutting in the water medium: 1 - framework, 2 - electromagnetic vibrator, 3 – metal bar, 4 – container filled with water, 5 -trapezium, 6 - engine, 7 – cane stem, 8 - converter, 9 – vibration blade edge, 10 – metal disk, 11 – transmission shaft.*

To determine the cutting force of the plants stem and to register the resulted data, resistance force gages were attached to the vertical bar of the blade and then dehydrated, moreover one of the resistance strain gages is installed at 45˚ angle towards the longitudinal axis of the vertical cylindrical sector, which enables to gain reliable data on the torque moment. Hinging schemes consisting of the strain gages (resistance elements) were connected with the ends of the resistance strain gages, which exclude any deformations and thermal effects. The obtained data were recorded and processed through the measuring and recording computer software ZetLab.

Fig. 2. *The general view of the experimental plant for the plants vibration cutting in the water medium.*

Results and discussions

Upon the conducted theoretical investigations [6, 7] some expressions have been derived, which enable to identify the blade of the apparatus cutting the resistance forces in the dense environment:

- vibrationless

tangent force: $\boldsymbol{T_x = \frac{8}{15}\rho\omega^3 \cdot \sqrt{\frac{\upsilon b}{\omega}} \cdot \ell^2 \cdot \sqrt{\ell}}$,

resistance moments: $\boldsymbol{M_1 = \frac{c\lambda\omega^2\rho\ell^4}{8} + 4b\sqrt{\mu\rho\omega^3} \cdot \ell^3}$, $\boldsymbol{M_2 = \frac{4}{9}\omega^3\rho\sqrt{\frac{\upsilon b}{\omega}} \cdot \ell^4 \cdot \sqrt{\ell}}$.

- in case of vibration

$\boldsymbol{T_x = 0}$, $\boldsymbol{M_2 = 0}$, and $\boldsymbol{M_1}$ is determined by the same formula,

where $\boldsymbol{\rho = 1000\mathrm{kg/m^3}}$ is the concentration of water medium, $\boldsymbol{\omega}$ is the rotation frequency of the rotor shaft ($\boldsymbol{0 \div 100s^{-1}}$), $\boldsymbol{\upsilon = 0.01cm^2/s}$ is the water kinematic viscosity, $\boldsymbol{b = 0.03m}$ is the width of the blade sheet, $\boldsymbol{l = 0.3m}$ is the length of the blade cutting edge, $\boldsymbol{\mu = 0.1kg/m \cdot s}$ is the coefficient of water viscosity, $\boldsymbol{\lambda = 0.001m}$ is the thickness of the blade sheet, $\boldsymbol{c = 1.45}$ is a coefficient, the value of which depends on the ratio of $\boldsymbol{b/\ell}$.

Placing the numerical values we'll have the following:

- Without vibration of the blade - $\boldsymbol{M_1 = 47.1N \cdot \mathrm{m}}$
- In case of vibration $\boldsymbol{M_1 = 1.3N \cdot \mathrm{m}}$.

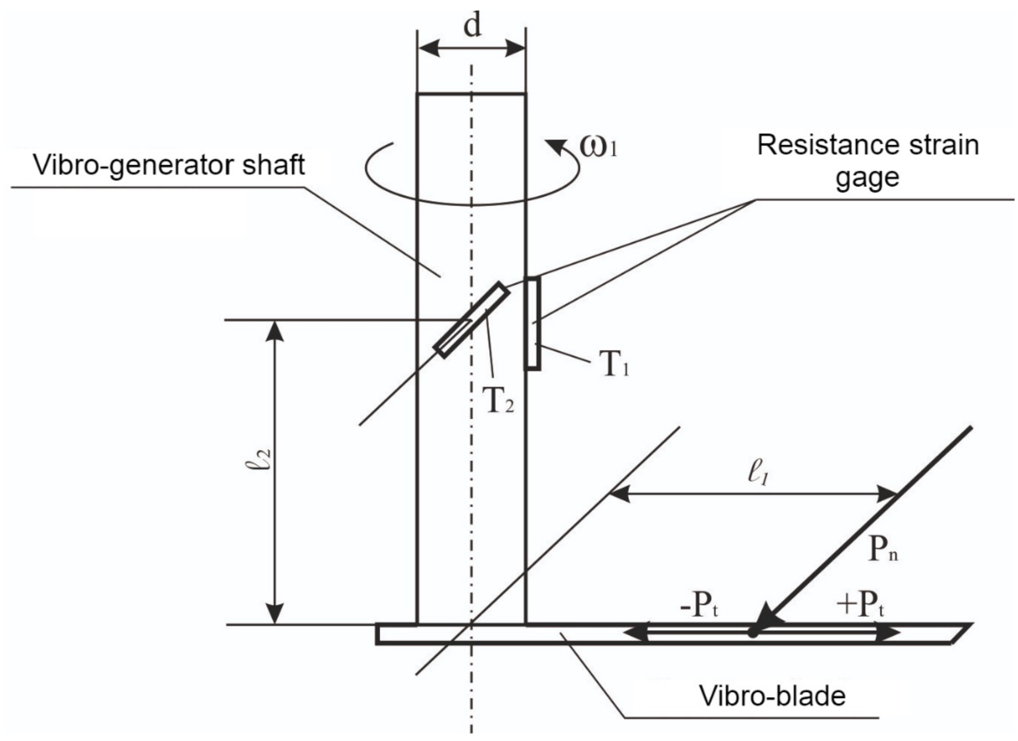

Fig. 3. *The scheme of experimentally identified force factors of vibro-cutting and system calibration.*

The calibration of the force factors in the experimental plant has been conducted in line with the methodology [8] developed by our research group according to the scheme depicted in figure 3. The relation of the measured force factors between the recorded deformations (strains) of the resistance strain gages is apparent. $\boldsymbol{T_1}$ strain gage records the tangent force factors at the blade cutting edge, the maximum regular strain in the sticking sector of transmitter:

$$\boldsymbol{\sigma_{max}} = \frac{\boldsymbol{M_z}}{\boldsymbol{W_z}},$$

where $\boldsymbol{M_z} = (\boldsymbol{T_x} \pm \boldsymbol{P_t}) \cdot \boldsymbol{l_2}$, is the bending moment in the mentioned sector, while $\boldsymbol{W_z} = \frac{\pi d^3}{32}$, is the resistance moment of the vibro-generator shaft.

$\boldsymbol{T_2}$ resistance strain gage records the deformation of the regular component of the cutting power ($\boldsymbol{P_n}$) and the twisting of the shaft in the vibro-generator affected by the resistance forces of the environment. The resistance strain gage is stuck at the angle of 45°, hence $\boldsymbol{\sigma_{max}} = \boldsymbol{\tau_{max}}$, besides:

$\boldsymbol{\tau_{max}} = \frac{\boldsymbol{M_t}}{\boldsymbol{W_\rho}}$, where $\boldsymbol{M_t} = \left(\boldsymbol{P_{n(c)}} + \boldsymbol{P_r}\right) \cdot \boldsymbol{l_1}$, $\boldsymbol{W_\rho} = \frac{\pi d^3}{16}$ is the polar resistance moment of the shaft sector.

In the result of conducted scientific investigations the most significant force factors have been determined: $\boldsymbol{M_1}$ **and** $\boldsymbol{P_t}$.

Figure 4 depicts the cutting oscillograms (for $\boldsymbol{M_1}$ moment) received from the $\boldsymbol{T_2}$ resistance strain gage in the air medium for two individual cane stems in case of vibro-blades with toothed cutting edge and flat edge and in case of oscillating amplitude along the cutting edge with the value of $\boldsymbol{a_x = 2.0mm}$ and with the frequency equal to $\boldsymbol{\omega = 60s^{-1}}$.

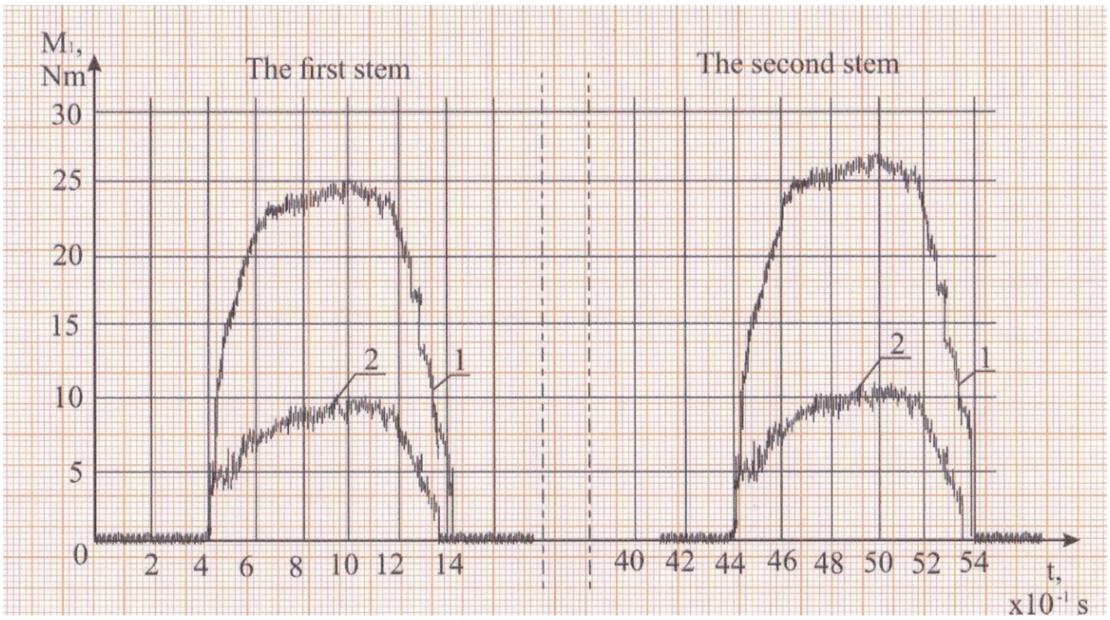

Fig.4. *The osscilloram sample of the resistance* $\boldsymbol{M_1}$ *moment caused by the regular component (P_n) of vibro-cutting (* $\boldsymbol{a_x = 2.0mm}$ *and* $\boldsymbol{\omega = 60s^{-1}}$ *) power in the air medium for one cane stem.*
1- Blade with flat cutting edge, 2- Blade with toothed cutting edge.

Figure 5 depicts the changing oscillogram of the tangent component in the cutting force of one cane stem (apart from each other, also the second stem) in air medium in case of parameters of $\boldsymbol{a_x = 2.0mm}$ and $\boldsymbol{\omega = 60s^{-1}}$.

It is noteworthy that the tangent component of the cutting force in case of flat cutting edge is smaller than that of recorded in case of toothed cutting edge.

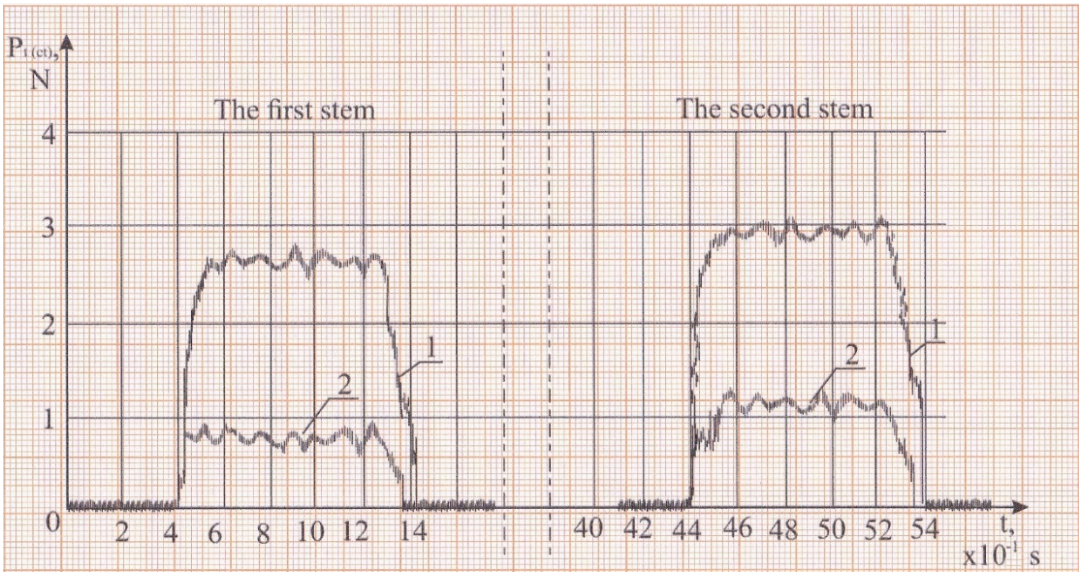

Fig.5. *The sample of changing oscillogram in the tangent component (P_t) of the vibro-cutting ($\boldsymbol{a_x} = \boldsymbol{2.0mm}$ and $\boldsymbol{\omega = 60s^{-1}}$)force for one cane stem in air medium.*
1- Blade with toothed edge, 2- blade with flat cutting edge.

Figure 6 illustrates the most important oscillogram in view of the discussed issue, that is the change of resistance $\boldsymbol{M_1}$ moment in the water medium without blade vibration (curve 1) and with its administration (curve 2).

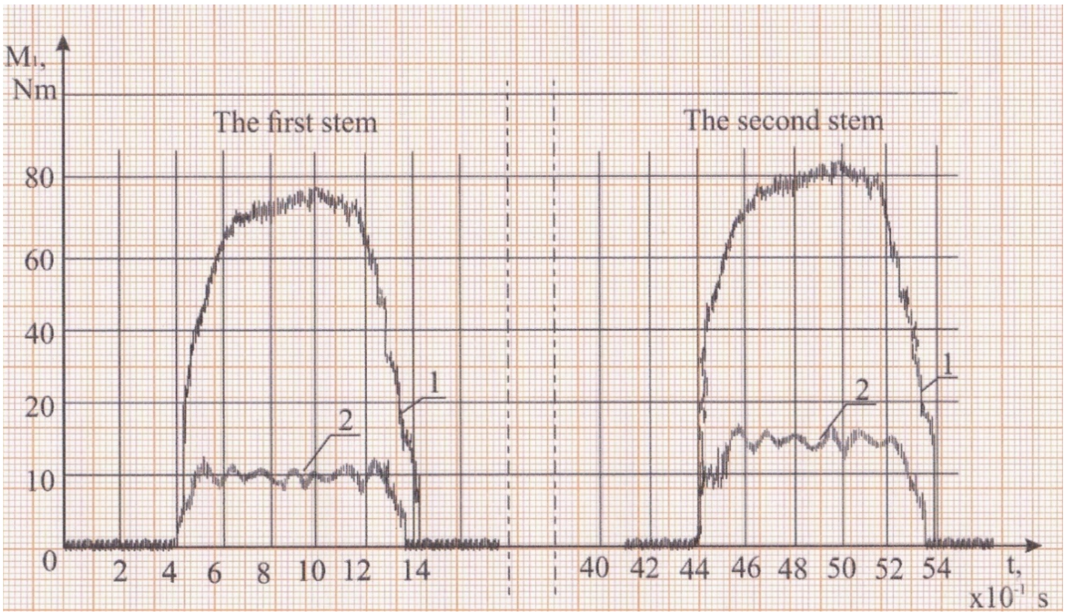

Fig.6. *The sample of the changing oscillogram of the resistance moment $\boldsymbol{M_1}$ affected by the environmental resistance forces and the regular component of the cutting resistance force for one cane stem in water medium.*

1-Without blade vibration (vibrationless) in the water medium, 2- with blade vibration in the water medium ($\boldsymbol{a_x} = \boldsymbol{2.0mm}$ and $\boldsymbol{\omega = 60s^{-1}}$).

As we can see from the last oscillogram, the resistance moment in water medium is about 10 times less in case of blade vibration as compared to that of observed in case of vibrationless cutting, besides, in case of oscillation frequency increase this difference becomes even larger. Thus, by increasing the oscillation frequency from $60s^{-1}$ to $90s^{-1}$, the mentioned difference amounts from 10 to 23 times.

As to the tangent component of the resistance forces in case of vibro-cutting, they hardly undergo any significant changes in water medium as compared to that of observed in air medium. The main point in the tangent component of the cutting forces is that it is about three times higher in case of the toothed blade in comparison with the index recorded in case of flat blade (Fig. 5), this being quite expected.

It is also quite clear that irrespective of the above mentioned, the cutting efficiency in case of the toothed blade grows up, as a result of which the regular cutting component, which determines the general resistance $\boldsymbol{M_1}$ moment, falls down in 2.5÷3.0 times.

Conclusion

Thus, in the result of the laboratory research experiments the most significant outcomes received through the theoretical researches have been mostly verified. Particularly, this is related to the fact that the cutting resistance forces in case of vibro-cutting in water medium, and hence the energy costs fall down in about 20 times. In case of vibro-cutting the toothed blades are effective, the application of which reduces the cutting resistance force factors in about 3 times, as compared to those observed in case of applying flat cutting edge blades.

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