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CONSTRUCTION SOLUTIONS IN MODERN FOOD STERILIZERS
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AN EFFICIENT HARVEST LINE FOR SHORT ROTATION COPPIES WITH A NEW MOWER-CHIPPER

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Abstract: The cultivation of short rotation coppice (SRC) such as poplar and willow on agricultural land is of increasing interest for farmers. But high investment costs, high processing costs, low flexibility of the machines as well as high machine weights are problems, which hinder an extensive implementation. Therefore, the development of a simple and low weight mower-chipper was started. The chipper was designed for mounting in front of medium sized standard tractors. The new developed machine has been tested in three harvest periods. Because of the very promising test results an industrial production is in preparation. To analyse the storage behaviour of wood chips different outdoor storage experiments were carried out at practice scale. Storage of coarse wood chips from the mower-chipper was compared with storage of fine chips produced by a forage harvester. Only small differences were found between both chip sizes.

KEYWORDS: SHORT ROTATION COPPIES, HARVEST, STORAGE, MOWER-CHIPPER

1. Introduction

The cultivation of fast growing trees (short rotation coppice - SRC) such as poplars and willows on agricultural land is of increasing interest in Europe. But efficient harvest technology for SRC crops is still an important question because appropriate machinery is not always available at reasonable costs. 

SRC harvesting lines for the supply of different sizes of woody biofuels have been developed, ranging from small wood chips produced with forage harvesters, chunks or billets to whole shoots or bundles of shoot produced with tractor-trailed shoot cutter-bundler machines. Basically, existing harvest technology can be classified into four groups:

− Log lines
− Shoot lines
− Chip lines
− Bale lines

Numerous publications can be found about all these harvesting technologies in the last decades (Stokes and Hartsough 1994; Hartsough et al. 1997; Scholz et al. 2008; Abrahamson et al. 2010). Advantages and disadvantages, costs and harvest capacities were presented and discussed.

Analysing the process chain in SRCs, it can be concluded that high investment costs for suitable harvest equipment, low flexibility regarding tree variety and cultivation scenario as well as high machine weight accompanied by problems during harvest and low capacities are some of the most important obstructions at present.

With respect to minimum process steps and low production costs, chip lines with mower-chippers are advantageous because mowing, chopping and conveying of chips on a transport unit can be performed by only one machine while driving.

Resulting from the unsatisfactory situation in harvesting technology for SRCs, a research project has been started to develop a simple and low weight universal mower-chipper for trees up to 15 cm stem diameter for single rows. The weight of the chipper should be low due to mount the mower-chipper in front of medium sized standard tractors.

For systematic development of a new working principle for the mower-chipper with these features, an answer for following questions had to be found:

− How can be a simple and robust cutter-chipper unit realized?
− How can be simple and save feeding of the cutter-chipper unit with trees realized?
− How to avoid falling down of trees in a horizontal position?

Additional to this questions further information have to be obtained:

− How is the storage behaviour of the chips characterised?
− What are the advantages or disadvantages of the mower-chipper in comparison to commonly used forage harvesters with special cutter-headers?

2. Material and Methods

2.1 Development of a new mover-chipper

The basic idea for the new mower-chipper unit is shown in Figure 1 and 2. To minimise the number of powered parts, the functions of mowing, chopping and conveying of chopped material were realised by a compact and simple mower-chipper unit (tool rotor) rotating in a robust housing. For tree mowing, the tool rotor of the prototype is designed as a disc saw with an outer diameter of 1300 mm. For chopping of severed stems, knives set on spacer blocks are installed on the upper side of the disk saw. Contrary to most mowing disks in other harvesters, the tool rotor is solid and not slotted, thus avoiding chips falling on the ground of the field. As a result of this arrangement, the theoretical maximum chip length is limited by the sum of the height of the spacer block and the chopping knife. The chop length can be altered by using spacer blocks of different heights. For an optimal chopping process, a counter bar is installed on the housing. During cutting and chopping the cut stems remain in an upright position by the help of the guiding arm and the star wheel. After chopping, the comminuted material is accelerated and moved to the outer edge of the housing at a rotation speed of 1000 rpm towards the discharge opening.
The mower-chipper was tested in three harvest season (fig. 3).

With respect to current standards and end user requirements regarding maximum chips size, the mower-chipper was adjusted to cutting length of 75 mm for the supply of coarse wood chips for later storage tests.

In comparison to the new developed chipper a self-propelled forage harvester from new Holland with a cutter-header (FR 9060 with SRC-header KUP 130FB) was used on the same test fields. The forage harvester produced usual fine chips because of the cutting drum inside the harvester.

2.2 Storage experiments

The wood chips from the mower-chipper and from the forage harvester were stored in two horizontal silos with 500 m³ in each pile (fig. 4). The silos were equipped with measuring columns for periodical sampling and continuous temperature measurements. Mass losses, mould contamination and moisture content were determined by extracting a column in the first 2 months of storage every 2 weeks, later every 4 weeks. Losses in dry matter were analysed with the help of balance bags. The moisture content of the chips from the balance bags was detected according to the oven dry method. In every column 12 balance bags and 3 temperature loggers (Tinytag TGP-4017 data logger with built-in temperature sensors) were embedded at 3 levels in 0.6, 1.4 and 2.2 m height from the ground.

The mould development was determined with the help of malt extract agar plates. The malt extract plates were analysed after 2 days of incubation at 37 °C to determine the extent of thermophilic mould contamination (Pecenka et al. 2014).

3. Results and discussion

The weight of the complete tractor-mounted mower-chipper, tested until March 2015, was about 1,200 kg. The tractor with the mower-chipper can be used as a single vehicle with a pulled trailer. Only one person is necessary to harvest trees. The field tests have shown that the basic working principle of mowing and chipping trees in an upright position has significant advantages. The breaking and uprooting of trees during cutting can be completely avoided. The stumps showed a clear cut surface after mowing with the circular saw. Trees with stem diameter up to 15 cm and with 10 m height could be successfully harvested in a 18 years old SRC (2 and 4 year rotation).

An effective speed of 3 to 5 km h⁻¹ was realized with the test unit. A performance of 0.42 ha h⁻¹ and a productivity of 12 t dm h⁻¹ were achieved in the year 2013. In 2015 the performance could be increase to 0.5 ha h⁻¹ at an average productivity of 15 t dm h⁻¹.

The mower-chipper produces with the used spacer blocks much coarser wood chips than forage harvesters. In contrast to the visual impression both chip bulks can be classified as wood chips of the class P45 according to CEN/TS 14961. Chips of the forage harvester are very close to the maximum content of fines allowed by the standard. The chips of the
mower chipper are close to the maximum content of oversized chips regarding the standard. The developments of moisture contents, dry matter losses, and temperatures in the two silos are shown in Figure 5 for the first 8 months in year 2013. The temperature in the coarse chip pile remained on a lower level and decrease earlier. The drying process started earlier in the pile with the coarse chips but both piles achieved the same moisture content at the end of the storage period. At the end of the storage period, the fine chip pile has showed mass losses of nearly 24% and the coarse chip pile has reached 27%. The higher porosity of the pile produced of coarse wood chips enables an improved natural aeration and drying of the storage. Connected to this improved aeration – more oxygen flow through the chips and improve the conditions for biological and chemical decomposition processes.

4. Conclusions
The new developed mover chipper is a suitable machine for harvest of trees from SRC. With the investigated harvester, trees with stem diameters up to 15 cm and with a 10 m height could be successfully harvested. The mover-chipper produces coarser chips in comparison to common forage harvesters with cutter-headers. The coarse chips from the mover chipper do not lead to lower losses during the storage period. It has been concluded that further investigations are necessary to understand the degradation processes during storage and to find out optimal chip sizes and storage techniques for SRCS.

References

![Figure 5: Development of dry matter losses, moisture content, pile and ambient temperature during 8-month storage of fine and coarse wood chips from poplar in 2013](image)
THE BATCH-COMBINED MINIMUM TILLAGE FARMING MACHINE

ПАКЕТНО-КОМБИНИРОВАННАЯ СЕЛЬСКОХОЗЯЙСТВЕННАЯ МАШИНА ДЛЯ МИНИМАЛЬНОЙ ОБРАБОТКИ ПОЧВЫ

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Abstract: The working members of the batch-combined machine for minimum tillage and crop tending are combined into two separate batches. By means of the first batch, there are performed simultaneously tilling and sowing operations, but the second is intended for surface tillage and crop tending. During just one field day, the machine is capable of performing 8…10 agricultural operations, and its working members can work in three modes: 1. Soil loosening without furrow slice overturning, when the main tillage unit (wedge) is in its working condition together with lateral knives (for the eroded soils); 2. Clod furrow slice pulverization and mixing, when the main tillage unit (wedge), lateral knives and rotary tiller are in their working conditions (for the non-eroded soils); 3. Cultivation of humid soils with a partial overturning of furrow slice, when the main tillage unit (wedge), lateral knives and rotary plough (instead of tiller) are in their working conditions. The cost of oil and lubricants and operating time are reduced by 2...2,5 times, and besides, the agrotechnical terms reduce considerably. The design formula for tillage output envisages both broken and unbroken soil strips. This formula can be also used for calculation of the machine output during cultivation, sowing, cutting the irrigation channels and so on. The proposed batch-combined machine can be also considered as energy-saving, resource-saving, environmental and advanced technology.

Key words: TILLAGE; CULTIVATION; FERTILIZER; HERBICIDE; IRRIGATION; KNIFE; WEDGE; PLIOUGH; ROLLER; SUBSOIL PLOUGH

1. Introduction

As is known, multiple field days of tillage combines for performing agricultural operations lead to considerable soil consolidation and its dispersion. Thereat, soil strength increases, capillarity and moisture capacity go down and seeding time increases that in turn, causes reduction in yields. It is therefore necessary to develop and put into operation the combined tilling machines allowing performing several agricultural operation and processes simultaneously during one field day.

In the light of the foregoing, we have developed the so-called batch-combined strip tilling and crop tending machine, which is capable of performing 8…10 agricultural operations simultaneously during just one field day. These operations are as follows: ploughing (rotary tillage and loosening), expansion and deepening of tilled strip for the purpose of expansion of feeding canals and weeding; tilled soils harrowing; sowing; injection of friable mineral fertilizers into soil (both underground and surface ones); cultivation of border strip; making irrigating channels; injection of organic and mineral fertilizers into soil (both underground and surface ones); cutaway of backs from the walls of border strips and throwing them into the tilled strip; injection of herbicides or sprinkling of plants with pesticides; breaking of clods and packing; soil furrowing and cutting of track for tractors large bogie wheels.

2. Preconditions and means for resolving the problem

The working member of strip tilling of soil comprises the passive (the main ploughing device – wedge) and active (rotator plough) working members, which working separately or simultaneously, perform strip tilling of soil. In this case, there cultivated not the full area, but just a soil strip of a certain width (b=15…30 cm) and depth (a=15…25 cm), which is intended for seeding or planting (Fig.1). But in other unbroken strips, soil “rests” and it will be tilled in the following years.

Fig. 1. Scheme of strip tilling of soil
1 – Broken strip; 2 – Unbroken strip; 3 – Irrigation mini channels; Seed.

It is known that the working members of soil tilling machines are shaped as a wedge, since for breaking of material by wedge by using the relatively less force, which is directed along the wedge, it possibly to obtain a large force, which breaks up material into several parts. Thus, the wedge is considered as an efficient working
The first batch’s working members operate in the following manner: by means of adjustor nuts 18 and 21 of the main plough, the soil layer lifted by the main plough is completed by means of lateral vertical knives 13 vertically on the both sides (Fig.3), but the expanding knives cut – cutaway of backs from the walls of the vertical knives 13 vertically on the both sides, the cutting of soil layer, its vertical lifting, loosening and movement on its surface toward the cutter knives. The cutting of soil layer lifted by the main plough is completed by means of lateral vertical knives 13 vertically on the both sides (Fig.3), but the expanding knives cut – cutaway of backs from the walls of the border strips with a certain angle, and expanding of tilled strip at the side of soil surface. When the soil layer moving on the main plough, reaches the cutter’s knives, there begins its breaking and throwing into empty soil, which is cut from behind. Throwing of clods is limited by metal net 25 fixed to bracket 20, on which after colliding of clod thrown by cutter’s knives with net, it will be more broken into the tilled strip, but the thin particle of soil, which will pass through the net, will lay on the surface of tilled soil and will provide an even top surface and thinness of particles. The filled out strip is harrowing by harrow 9 and then there occurs seeding. By means of anchoring seeder 8 and subsoil disrupter 10, which is fixed to the top of the main plough 11, the deepening of tilled strips’ bottoms at the depths of 5…8 cm is completed. Between the lateral knives 13, there is inserted the shaft 15, on which by means of splines there is mounted substitute in kind of clod (soil layer) ripper, an active working member 14, for example cutter or rotary plough. Besides, the driving shaft 15 with reduction gear unit 17 and cardan drive 16 sets in driving from power take-off shaft of tractor.

The designations of the first batch’s working members and other elements are shown in Fig. 1.

The second batch’s working members operate in the following manner: together with operation of the first batch’s driving members, there operate the second batch’s driving members as well. In particular, the soil cultivation in the border strips is carried out at a small depth (1,5…3 cm) by means of arrow-like universal hoes 26, or by herbicides 36. Two hoes are fixed to cutter 27, and one – to cross member of machine’s frame 1.

The backs of border strip cutaway by means of tilled strip expander 12 (Fig.2, Fig. 3), are cut again by knife 27 with a certain width and angle, and then by means of blade 28 fixed to it, are throwing into the tilled strip that results in creation of cut irrigating mini channel 44 (Fig. 2), which can be used as an irrigator by tracks as well as for drop irrigation, for placing of drop rubbery hoses in it.

By means of needle-like gear breaking-ramming rollers 33, on the strip tilled surface there could happen breaking of clods and ramming, but with a lateral ramming roller (or sledge-like shield) 34 mounted on it, there is performed ramming of slopes of irrigating channels (or restriction of ground brought down into the irrigating track).

By means of guiding slot cutters 29, on tracks of tractor wheels in the border strips there could happen cutting of slots at a depth 25…30 cm (during the first passage – until 20 cm, during the second and third one – until 5,5 cm), which are intended for better orientation during motion and increasing service speeds during execution of following operations, during the repeated passage, as well as for better irrigation of soil near the roots by using the mini channels.

On tracks of tractor wheels, whereupon the soil the slots are cut, by means of plough working member 39 (Fig. 3), there could be cut the track with a depth of 4…6 cm and width of 20…30 cm, which is intended for quick finding and orienting of the moving direction of tractor aggregate during the repeated passage for execution of following operations (constant track).

**Fig. 2. The Scheme of Batch-Combined Machine for Strip Tilling-Sowing and Crop Tending:**

**The first batch’s working members:** 1. Frame; 2. – Suspension; 3. - Receptacle for seeds and fertilizers; 4. – Sowing device for seeds and fertilizers; 5. – Fertilizer pipeline; 6. – Seed pipeline; 7. – Seeder securing bracket; 8. – Anchoring seeder; 9. – Spike-tooth harrow; 10. - Subsoil disrupter; 11. – The main plough (wedge); 12. – Lateral expanding knives; 13. – Lateral vertical knives; 14. – Cutter knives; 15. – Cutter shaft; 16. - Cardan drive; 17. – Cutter reduction gear unit; 18. – Adjusting screw with oval slot for soil entry angle of the main plough; 19. -  Securing bracket for plough member on the frame; 20. – Bracket; 21. – Foot screw; 23. – Journal and adjusting wheel; 24. – Harrow and seeder securing bracket; 25. – Clod throwing limiting net. **The second batch’s working members:** 26. – Cultivator arrow-like universal hoe;
Injection of herbicides 36 or aerosol nutrition of plants is carried out by means of sprayer 35.

By means of ploughing driving member of batch-combined machine, it is possible to carry out strip tilling at three modes as follows: 1. Loosening of eroded soil, with no overturning of clod, when the cutter 14 is turned off and is in operation, together with the main plough 11, lateral vertical knives 13, expanding knives 12 and subsoil disrupter 10; 2. Tilling of non-eroded soils, with breaking and mixing of clods, when the main plough 11, lateral vertical knives 13 and tilled strip expanding knives 12, subsoil disrupter 10, and an active driving member – cutter 14 are in operation; 3. Cultivation of humid soils by partial overturning of clod, when in operation are the main plough 11, lateral vertical knives 13 and expanding knives 12, subsoil disrupter 10 and rotary plough, which will be mounted on the shaft 15 at the place of cutter 14.

**Fig. 3. Mounting Arrangement of Driving Members of Batch-Combined Machine:**
Based on the above stated considerations, it is possible to make the following conclusions:

In case using the wedge as a main ploughing unit, for soil loosening there is required a force, which is by several times less than when using other tilling working members, for example, when using ordinary ploughs. Hence, the cost of oil and lubricants and operating time are reduced by 2...2,5 times. That is why it is considered as energy-saving and resource-saving working member (machine).

When using the combined tilling working members we developed, the hourly efficiency at strip tilling of soil can be calculated the formula, which we also developed recently (according to Fig. 1)

\[ W = 0.36 V_p (B_0 (n-1) + B_p n) \]

where, \( V_p \) – is an operating velocity of machine, m/sec; \( B_0 \) – is unbroken row’s width, m; \( B_p \) – one plough-share coverage width, m; \( n \) – number of ploughs. As is seen from the formula, the efficiency of the batch-combined tilling machines is considerably higher than during tilling with ordinary ploughs and consequently, lower is the cost of oil and lubricants and environmental pollution that makes them more profitable to farmers and country. So it should be considered not only energy- and resource-saving technology, but the nature-oriented technology (machine) as well.

3. Conclusion

Since the soil between the broken rows “rests” and it will be cultivated in the following years, the thickness of the fruitful in the surface layer of mellow humus layer will be preserved, and the development of the erosive processes will slow down that will result in an increase in productivity. That is why the proposed technology even in a greater degree is a nature-oriented technology.

Due to fact that the share of the eroded soil in the entire area of all arable lands is high, cultivation of soils of various complexity by means of the combined working members at the appropriate modes (there are given above three types of modes with regulation of the tilt angle of a main ploughing unit – wedge), it will be possible to avoid developing the wind and watery-erosion processes. In addition, the resistance of soil during its cultivation by agricultural machine will be reduced, that will result in reducing capacity power of tractor engine, as well as the cost of oil and lubricants required for strip tilling of soil. The released power of engine can be used for increasing the plough-share coverage and operating velocities of machine.

Thus, as a whole, such a soil tilling technology should be considered as energy-saving, resource-saving, nature-oriented rational and advanced technology.

4. Literature

THEORY OF THE SEQUENTIAL OSCILLATIONS OF THE SUGAR BEET ROOT DURING ITS VIBRATING DIGGING FROM THE SOIL

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Annotation. In order to determine the optimal design and kinematic parameters of vibrational digging harvest technology of the sugar beet roots in relation to the physical and mechanical soil properties it is necessary to develop a new theory of the sequential oscillations of the sugar beet root during its vibrating digging from the soil. Such theory should be based on a deep study of the mechanism of force interaction of digs plough shares vibration working body with the body beet root and its further translational vibrations in the soil, as in an elastic medium.

In a first stage we have developed an equivalent scheme of the above mentioned harvest technology, there were determined all forces acting on sugar beet root (conic approximation) and surrounding soil (in depth of movement of the digging plough shares and deeper – point of relative gripping), there were given kinematic parameters of the oscillating action on the sugar beet root, and axes were introduced.

Next there were composed of linear second order differential equations with constant coefficients with the right parts, which describe the free and forced vibrations of beet root and its point of attachment along the axes, together with the surrounding soil root in the first stage extraction.

Results obtained by using of systems of differential equations obtained on the PC have enabled to formulate the law of motion of beet root in the process of direct extraction from the soil vibration, as well as calculate the frequency and amplitude of free and free accompanying vibrations and amplitudes of forced vibrations root as a rigid body in an elastic medium.

According to calculations, the centre of mass of root through 0.025 s to implement horizontal translational movement to a distance of 50 mm at a frequency of the disturbing force 10 ... 20 Hz vertical and translational movement over a distance of 35 mm, at the same frequency vibrations and soil hardness \( c_{v} = 2 \cdot 10^5 \) N/m^2.

KEYWORDS: OSCILLATING DIGGING MECHANISM, SUGAR BEET ROOT, SOIL, EQUIVALENT SCHEME (LAYOUT), DIFFERENTIAL EQUATIONS, OSCILLATIONS, AMPLITUDE, FREQUENCY.

Introduction. Research of the new technological processes and developing of the improved working mechanisms for sugar beet harvest can be considered as a very important task related to sugar beet cropping systems as the sugar beet harvest is very time-consuming and has very high energy requirements. Widely used vibration digging working bodies of beet roots have significant advantages in comparison with other types of working mechanisms in terms of quality and energy criteria. However, this is achieved in a relatively favourable harvest conditions when the soil moisture content and soil hardness have relatively optimal values, and the straightness of the rows of crops is relatively high. In the case where these parameters are not, vibration digs working bodies not only provide the desired agronomic indicators of quality of cleaning and overall energy intensity parameters, and in some cases do not become operational. Therefore, the research and development of optimal parameters of vibration digging working bodies for sugar beet harvesting machinery is an actual scientific and technical problem.

Prerequisites and means for solving the problem. The solution of the problem can be carried out on the basis of deep theoretical studies of vibrating vibration interaction of the digging working body and the body of beet root, which is in the soil, in an elastic medium, and in fact it is fixed. To do this, it is very necessary to develop a mathematical model that describes the behaviour of the beet root crop at different stages of its interaction with the vibrating ploughshares digging working body of quality of cleaning and overall energy intensity parameters, and in some cases do not become operational. Therefore, the research and development of optimal parameters of vibration digging working bodies for sugar beet harvesting machinery is an actual scientific and technical problem.

Solving of a given problem. A mathematical model of a vibrating digging of the beet root will be developed. To do this, analytically will be studied oscillations of the beet root with the point 0 about its conditional fixing in the soil in the longitudinal and vertical plane is the first phase of its removal from the soil. Data characterizing of the root will be considered as translational, and therefore for the theoretical study of this process will be sufficient to investigate the vibratory motion of any one of its points, for example, the fixed point 0. As we consider this oscillation process with a symmetric capture of the sugar beet root by vibration digging working body, then for making differential equations that will describe this oscillatory process, we first construct an equivalent scheme of interaction of the sugar beet root with working body shown in Fig. 1.

Because sugar beet root is firmly bound to the soil, it will be oscillated together with the surrounding soil, which is below the cutting edges of the plough shares vibration digging out the working body is generally not deformed and strong enough. We will mark the weight of the soil as \( m_{\text{гр}} \), while its weight \( G_{\text{гр}} \) is equal to \( G_{\text{гр}} = m_{\text{гр}}g \), where \( g \) – acceleration due to gravity.

We will present the beet roots as a cone-shaped body, the apex angle is equal 2\( \gamma \). Simulation of oscillatory process will be considered in a fixed Cartesian coordinate system \( Ox_yz \), whose origin is at the point 0 of assigned root. We take into account the possible deviation from the vertical root at a slight angle \( \theta \). We introduce an additional coordinate system \( O_{x'y'z'} \), the axis \( O_{x'} \) of which is inclined from the axis \( Ox \) by an angle \( \theta \), the axis \( O_{x'} \) coincides with the axis \( O_{y'} \), the axis \( O_{z'} \) also rejected axis \( Oz \) by angle \( \theta \).

From vibrating digging working body there acts a vertical disturbing force \( Q_{\text{d}} \) that varies harmonically like this:

\[
Q_{\text{d}} = H \sin \omega t, \tag{1}
\]

where \( H \) – the amplitude of the disturbing force, \( \omega \) – the frequency of the disturbing force, s^-1.

This force plays a major role in the process of deformation of the soil in the area of digging out the working channel and direct digging beet root and it is applied to it on both sides in the points \( K_{1} \) and \( K_{2} \) of the digging plough shares \( A_{1}B_{1}C_{1} \) and \( A_{2}B_{2}C_{2} \), and therefore it is represented in the diagram by two components, which are equal to:

\[
Q_{\text{d}1} = Q_{\text{d}2} = 0.5H \sin \omega t. \tag{2}
\]

Forces \( Q_{\text{d}1} \) and \( Q_{\text{d}2} \) are applied at a distance \( h \) from the origin (the point O of assigned root fixation) and they cause vibrations in the longitudinal vertical plane, destroy root connection with the soil and create the conditions for its excavation from the soil. In the future, these forces are decomposed into components.

Since the vibration digging working body moves forward in the
direction of the axis $O_x$ at a speed $\vec{V}$ relative to root beet, which is actually fixed in the soil, at the moment of capture him act as side drivers $\vec{P}_1$ and $\vec{P}_2$ which then are also decomposed into components.

We form the differential equation of motion of the sugar beet root. In vector form, this differential equation will have the following form:

$$\left( m_i + m_p \right) \ddot{x}_i = N_{ix} + N_{ix} + L_{ix} + L_{ix} + \vec{F}_i + \vec{F}_i + \vec{E}_i + \vec{E}_i + + \vec{G}_i + \vec{G}_i + \vec{R}_i + \vec{R}_i ,$$  \hspace{1cm} (3)

where $\ddot{x}_i$ – acceleration of the sugar beet root (its relative point $O_i$).

For a theoretical study of the oscillatory process, we write the differential equation (3) in the projections on the axes of the Cartesian coordinate system $Ox_{12}$, $\gamma \beta$. It should be noted that, since the projection of normal reactions $N_{ix}$, $L_{ix}$ for the working surfaces of ploughshares $A_1B_1C_1$ and $A_2B_2C_2$ on digs axes $O_{12}$ are equal in magnitude and opposite in direction, this oscillation process is actually performed in the plane $O_{12} \gamma \beta$ (with a symmetrical capturing of a body of the sugar beet root) and therefore vector equation (3) reduces to a system of two equations of the form:

$$\left( m_i + m_p \right) \ddot{x}_i = N_{ix} + N_{ix} + L_{ix} + L_{ix} - F_{ix} + + E_{ix} - F_{ix} + + E_{ix} - G_{ix} + \vec{R}_i + \vec{R}_i ,$$

$$\left( m_i + m_p \right) \ddot{y}_i = N_{iy} + N_{iy} + L_{iy} + L_{iy} - F_{iy} + + E_{iy} - F_{iy} + + E_{iy} - G_{iy} + \vec{R}_i + \vec{R}_i .$$  \hspace{1cm} (4)

We define the values of the projections of forces that are part of the system of equations (4).

The projection of the normal components $N_{ix}$ and $N_{iy}$ on the axle $Ox_i$ are defined as follows:

$$N_{ix} = N_{iy} = \frac{N_{iy} \cos \gamma}{\sqrt{\sin^2 \gamma + 1 + \tan^2 \beta}} = \frac{Q_{ix} \cos \delta \tan \gamma}{\sqrt{\sin^2 \gamma + 1 + \tan^2 \beta}} .$$  \hspace{1cm} (5)

The projection of the normal components $L_{ix}$ and $L_{iy}$ on the axe $Ox_i$ will be as follows:

$$L_{ix} = L_{iy} = \frac{L_{iy} \tan \gamma}{\sqrt{\sin^2 \gamma + 1 + \tan^2 \beta}} = \frac{P \sin \gamma \tan \gamma}{\sqrt{\sin^2 \gamma + 1 + \tan^2 \beta}} .$$  \hspace{1cm} (6)

For the projections of components $F_i$ and $F_i$ of the friction forces we have the following expressions:

$$F_{ix} = F_{iy} = F_i \cos \delta \tan \gamma ,$$  \hspace{1cm} (7)

or, taking into account, that

$$F_i = F_i = (0.5 f H \cos \delta \sin \omega t + f \gamma P \sin \gamma) \sin \left( \alpha_{ix_{max}} \sin \omega t - \gamma \right) ,$$

we receive:

$$F_{ix} = F_{iy} = (0.5 f H \cos \delta \sin \omega t + f \gamma P \sin \gamma) \times$$

$$\times \sin \left( \alpha_{ix_{max}} \sin \omega t - \gamma \right) \cos \delta \sin \gamma ,$$

$$\omega t \in \left[ 2 k \pi, (2 k + 1) \pi \right] , \hspace{0.5cm} k = 0, 1, 2, \ldots$$

Projection friction forces components $E_i$ and $E_i$ on the axis $Ox_i$ after the same similar changes will be equal to:

$$E_{ix} = E_{iy} = (0.5 f H \cos \delta \sin \omega t + f \gamma P \sin \gamma) \times$$

$$\times \cos \left( \alpha_{ix_{max}} \sin \omega t - \gamma \right) \cos \delta \sin \gamma ,$$

$$\omega t \in \left[ 2 k \pi, (2 k + 1) \pi \right] , \hspace{0.5cm} k = 0, 1, 2, \ldots$$

The force $R_i$ is projected on the axis $Ox_i$ in full size. It is determined according to the following expression:

$$R_i = \frac{c \pi \h^2 \sin \gamma}{2 \cos^2 \gamma} + x_i ,$$  \hspace{1cm} (10)

where $c$ – coefficient of elastic deformation of the soil (the ratio of the first Winkler coefficient to the contact area), i.e., value that indicates how much stress increase at the contact surface with the ground when moving the sugar beet root per unit length perpendicular to the axis of the root, N/m.

The projection of the normal components $N_{ix}$ and $N_{iy}$ on the axle $Ox_i$ will be as follows:

$$N_{ix} = N_{iy} = \frac{N_{iy} \cos \beta}{\sqrt{\sin^2 \beta + 1 + \tan^2 \beta}} = \frac{Q_{iy} \cos \delta \sin \beta}{\sqrt{\sin^2 \beta + 1 + \tan^2 \beta}} .$$  \hspace{1cm} (11)

The projection of the normal components $L_{ix}$ and $L_{iy}$ on the axle $Ox_i$ will be as follows:

$$L_{ix} = L_{iy} = \frac{L_{iy} \sin \beta}{\sqrt{\sin^2 \beta + 1 + \tan^2 \beta}} = \frac{P \sin \beta}{\sqrt{\sin^2 \beta + 1 + \tan^2 \beta}} .$$  \hspace{1cm} (12)

The projections of components $F_i$ and $F_i$ of the friction forces on the axis $Ox_i$ will be as follows:

$$F_{ix} = F_{iy} = F_i \sin \delta ,$$  \hspace{1cm} (13)

or

$$F_{ix} = F_{iy} = (0.5 f H \cos \delta \sin \omega t + f \gamma P \sin \gamma) \times$$

$$\times \sin \left( \alpha_{ix_{max}} \sin \omega t - \gamma \right) \sin \delta ,$$

$$\omega t \in \left[ 2 k \pi, (2 k + 1) \pi \right] , \hspace{0.5cm} k = 0, 1, 2, \ldots$$

The projections of components $E_i$ and $E_i$ of the friction forces on the axis $Ox_i$ are equal to zero on any interval ($E_i = E_i = 0$).

Expression for $R_i$ was obtained by the following way:

$$R_i = \int_{0}^{\gamma} c \varepsilon z \gamma z \gamma \sin \gamma \sin \gamma dz = \frac{c \pi \h^3 \sin \gamma \sin \gamma}{\cos \gamma} ,$$  \hspace{1cm} (15)

and is the basis for the restoring force in the given oscillatory process. Thus, $c_i$ – the elastic deformation coefficient of the soil, which shows how increased is the force on the contact surface of the displacement per unit of contact surface area, N/m².

Substituting the expressions (5), (6), (8), (9), (10), (11), (12), (14) and (15) in the differential equations (4), we obtain the following system of differential equations:
In order to simplify the resulting system of linear differential equations, we have obtained the following notation:

\[
(m_k + m_p) \ddot{x}_i = 2Q_k \cos \delta \gamma + \frac{2P_i \sin \gamma \gamma}{\sqrt{f^2 \gamma + 1 + f^2 \beta}} - \frac{f \cos \delta \sin \alpha_{k_{\text{max}}} \sin \omega t - \gamma}{\cos \gamma_i (m_k + m_p)} \dot{x}_i ,
\]

\[
\begin{align*}
\{ f H \cos \delta \sin \alpha_{k_{\text{max}}} \sin \omega t + 2 f P_i \sin \gamma \gamma \times \\
\cos \delta \sin \gamma + (f H \cos \delta \sin \alpha_{k_{\text{max}}} \sin \omega t + 2 f P_i \sin \gamma \gamma) \times \\
\cos \alpha_{k_{\text{max}}} \sin \omega t - \gamma \sin \gamma_i \times \\
(\cos \gamma_i (m_k + m_p) ) \times \\
(1 - f P_i \cos \delta \sin \gamma \sin \gamma_i ) \times \\
(\cos \gamma_i (m_k + m_p) ) \times \\
(\cos \gamma_i (m_k + m_p) ) \times \\
(\cos \gamma_i (m_k + m_p) ) \times \\
(\cos \gamma_i (m_k + m_p) ) \times
\end{align*}
\]

\[
(16)
\]

The oscillation frequency in the \( O_{x_1} \) axis direction is equal \( k \) and is defined by the expression:

\[
k_k = \frac{h_i}{\cos \gamma_i \sqrt{2(m_k + m_p)}} .
\]

(19)

The oscillation frequency in the \( O_{z_1} \) axis direction is equal \( k \) and is defined by the expression:

\[
k_k = \frac{1}{\cos \gamma_i \sqrt{2(m_k + m_p)}} .
\]

(20)

Amplitudes of the free accompanying oscillations in the direction of \( O_{x_1} \) and \( O_{z_1} \) axis, as it can be seen from the expression (27), will be respectively:

\[
B_{k_k} = \frac{A_{H_2} \sin \omega t + B_{P_2} \sin \omega t}{k_i (k_i^2 - \omega^2)} ,
\]

(21)

\[
B_{k_k} = \frac{A_{H_2} \sin \omega t + B_{P_2} \sin \omega t}{k_i (k_i^2 - \omega^2)} ,
\]

(22)

Frequency of forced oscillations is equal to the frequency of the disturbing force and is equal \( \omega \). The amplitude of the forced oscillations of sugar beet root in the direction of the \( O_{x_1} \) and \( O_{z_1} \) axis and as can be seen from the expressions (27), are respectively:

\[
(23)
\]

\[
(24)
\]

After substituting the expressions (18) – (25) in a system of linear differential equations (17), they take the following form:

\[
x_i + k^2 x_i = A_{H_2} \sin \omega t + B_{P_2} ,
\]

(26)

\[
z_i + k^2 z_i = A_{H_2} \sin \omega t + B_{P_2} - g ,
\]

After determination of the arbitrary constants there was obtained a law of the translational vibratory motion of sugar beet root with its fixing point (O) in the direction of axes \( O_{x_1} \) and \( O_{z_1} \):

\[
(27)
\]

\[
(28)
\]

\[
(29)
\]

\[
(30)
\]

In order to simplify and linearization, there was obtained a system of linear differential equations that describes the process of extraction of sugar beet roots from the soil in the first stage:

\[
(m_k + m_p) \ddot{x}_i = 2Q_k \cos \delta \gamma + \frac{2P_i \sin \gamma \gamma}{\sqrt{f^2 \gamma + 1 + f^2 \beta}} - \frac{f \cos \delta \sin \alpha_{k_{\text{max}}} \sin \omega t - \gamma}{\cos \gamma_i (m_k + m_p)} \dot{x}_i ,
\]

(17)

\[
(18)
\]

\[
(23)
\]

\[
(24)
\]

\[
(25)
\]

\[
(m_k + m_p) \ddot{z}_i + c_r h_i \sin \gamma_i \ddot{z}_i = \frac{\cos \delta \gamma \beta}{\sqrt{f^2 \gamma + 1 + f^2 \beta}} + \frac{2P_i \sin \gamma \gamma}{\sqrt{f^2 \gamma + 1 + f^2 \beta}} - \frac{f \cos \delta \sin \alpha_{k_{\text{max}}} \sin \omega t - \gamma}{\cos \gamma_i (m_k + m_p)} \dot{z}_i + c_r h_i \sin \gamma_i \dot{z}_i ,
\]

\[
(26)
\]

\[
(27)
\]

\[
(21)
\]

\[
(22)
\]

\[
(28)
\]

\[
(29)
\]

\[
(30)
\]
\[
\begin{align*}
\frac{A_H}{k_1^2 - \omega^2} & \quad \frac{A_H}{k_2^2 - \omega^2}.
\end{align*}
\]  

(31)

Integrating the obtained differential equations and determining the values of the arbitrary constants we obtain the variation of the velocity of the vibratory motion of the sugar beet root as a function of time \( t \) in the direction of the axes and \( O_1x_1 \) and \( O_2z_2 \): respectively:

\[
\begin{align*}
\dot{x}_1 &= \frac{B_P P}{k_1} \sin k_1 t - \frac{A_H}{k_1^2 - \omega^2} \cos k_1 t + \frac{A_H}{k_1^2 - \omega^2} \cos \omega t, \\
\dot{z}_1 &= \frac{B_P P - g}{k_2} \sin k_2 t - \frac{A_H}{k_2^2 - \omega^2} \cos k_2 t + \frac{A_H}{k_2^2 - \omega^2} \cos \omega t,
\end{align*}
\]  

\[
\begin{bmatrix}
\omega t \in 2k\pi, (2k + 1)\pi \\
0, 1, 2, \ldots
\end{bmatrix}
\]

(32)

Thus, there were done all the analyses of the translational oscillations of the sugar beet root together with the point \( O \) of its fastening in the conditioned soil in a longitudinal vertical plane at the first stage of its removing from the soil, with a symmetrical nip.

In order to provide numerical calculations we can use the values of the required input data according to the information given in [4-6]. The following data have been used: the weight of the sugar beet root \( m_1 = 0.9 \) kg; the weight of the soil surrounded the sugar beet root \( h_s = 0.45 \); length of the sugar beet root \( h_s = 0.25 \) m; the angles of triangular wedges of the vibration digging working body: \( \gamma = 14^\circ; \beta = 52^\circ \); the coefficient of friction of steel on the surface of the sugar beet root \( f = 0.45 \); the amplitude of the disturbing force: \( H = 500 \) N; the value of the lateral driving force \( P_1 = 400 \) N; maximum deflection angle of the vector of the friction force from the vector of the minimum value of this force: \( \delta \max = 30^\circ \); coefficients of the elastic deformation of the soil: \( c_1 = 2 \times 10^5 \) H/m; \( c = 3 \times 10^5 \) H/m; the oscillation frequency of the vibration of the ploughshares digging working body: \( \nu = 15 \) Hz; taper angle of sugar beet root: \( \gamma_1 = 15^\circ \); dihedral angle \( \delta \) between the working surface of ploughshare and the lower base of triangular wedge is determined according to the expression:

\[
\delta = \arctg \frac{\cos \beta}{\sin \beta \cos \gamma}.
\]

Calculations were carried out according to the developed program on the PC by using software Mathcad.

It is necessary to specify in advance that it will be of considerable interest of calculations of the frequencies and amplitudes of the oscillations of sugar beet roots in the soil as a rigid body in an elastic medium, depending on the changes in the coefficient of elastic deformation of the soil, because it is done in a variety of soil conditions, as a rule, carried out the actual processes of harvesting of sugar beet roots.

According to [5], the elastic deformation coefficient of the soil can vary within the range from \( 2 \times 10^5 \) up to \( 30 \times 10^5 \) N/m².

The results of these calculations provided on a PC are shown in the form of graphs in Fig. 2 depicting the law translational vibrations of the sugar beet root (together with the point \( O \)) as a rigid body fixed in soil, obtained from the analytical dependences (27) and (32) for several values of the coefficients of the elastic deformation of the soil \( c_1 \) and \( c \) (\( H = 500 \) N; \( P_1 = 400 \) N; \( \nu = 15 \) Hz).

As noted in [5], for the partial destruction of bonds of the sugar beet roots with the soil it is necessary to ensure its initial lifting to a following distances: 8.6 mm for bigger sugar beet roots; up to 4 mm for smaller sugar beet roots. For the complete destruction of all ties of the sugar beet roots with the soil it is necessary to rise sugar beet roots to a height of 12-25 mm.

Thus, obtained analytical values of the amplitudes of the oscillations of sugar beet root, using the input data of the above, as can be seen from the graphs (Fig. 2), fully ensure the destruction of relationships of the sugar beet roots with soil and create all conditions for their complete removal from the soil and transfer to the cleaning working mechanisms of the sugar beet harvester.

**Results and Discussion.**

There was developed a new mathematical model of oscillations of sugar beet root as a rigid body in an elastic medium with a symmetric its capture by vibrating digging working body (capture beet root crop is carried out simultaneously by two digging ploughshares). There was formulated also a system of differential equations of translational vibrations of a sugar beet root body together with the point of its conditional fixing and together with the surrounding soil.

Solution of the obtained system of differential equations made it possible to find the law of the oscillatory process of the sugar beet root in the soil with a vibrating digging it out of the soil, as well as analytical expressions for calculating the frequencies, free amplitudes and free accompanying vibrations and amplitudes of forced vibrations of the sugar beet root as a rigid body in an elastic medium.

According to numerical calculations carried out on a PC by using the developed program, the centre of mass of the sugar beet root is able to move during 0.025 s around the axis \( O_1x_1 \) at a distance of 50 mm at a frequency of the disturbing force \( \nu = 15 \) Hz, and the axis \( O_2z_2 \) at the same frequency of the disturbing force \( \nu = 15 \) Hz at a distance of 35 mm (\( c_1 = 2 \times 10^5 \) H/m²), at a distance of 25 mm (\( c_1 = 3 \times 10^5 \) H/m²), and at a distance of 15 mm (\( c_1 = 2 \times 10^5 \) H/m²).
Conclusion.

It can be stated that the calculated values of the amplitudes of the oscillations of the beet root as a rigid body in an elastic medium with conventional fastening point for the kinematic modes provide full destruction of the root ties with the soil and create the conditions for next direct extraction of the sugar beet root from the soil.

References.

MULTI-FUNCTION DEVICE OF A CANAL CLEANER
FOR PERFORMING A COMPLETE CLEANING OF DRAINAGE CANALS

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Abstract: We offer a multi-functional operating element of rotary type for a channel cleaner, which is capable of performing the entire cycle of cleaning household water reservoirs (ponds), in particular: 1. due to the compound rotor: 1.1. mow and chop the crop; 2. due to the implementation of detachable body: 2.1. mill and transport “dry” soils using a jet of air; 2.2. pump water; 2.3. extract and transport the soil from under the water; 3. due to the installation of the teeth on the lower movable part of the body: 3.1. work as a clamp grapple to remove garbage from water reservoirs (ponds).

The basis of multifunctionality of this invention is in the principle of implementation of the maximum number of hidden abilities of the initial technical system, its rotor, framing, manipulator parts, which implies the subsequent creation of a reclamation robot.

Keywords: WATER RESERVOIRS, CLEANING, OPERATING ELEMENT (WORKING BODY), SOILS, MILLING CUTTER, THROWER, PUMP, GRINDER, MULTIFUNCTIONALITY

1. Introduction

Care for water supply channels occupies a significant place in the reclamation activities, because without proper maintenance these facilities are non-functional. Cleaning of farm reservoirs includes several operations:

- mowing, grinding and removal of vegetation;
- immediate removal of sandbar soils;
- removal of large inclusions.

The following operations should be performed:

- in dry soils;
- in waterlogged soils;
- under water.

For each operation, and for each option of soil conditions it is required a special operating element (mower, milling cutter, pump and so on. Thus, it is necessary to have a set of different devices, and each time to install them on the base machine, using transport and lifting equipment, time and manual labor.

To reduce the complexity of cleaning the channels by eliminating secondary operations and by increasing the flexibility of the cleaning process, we offer multi-functional device for the canal cleaner, which can be adapted to various operations and ground conditions.

2. The problem solution

It is able to:

- due to the compound rotor [1], (fig. 1):

  fig. 1. Compound rotor multi-function device.

  - mow and chop the crop (fig. 2);

- due to the implementation of detachable body[2], (fig. 3):

  fig. 2. Scheme cutting vegetation in cross section a rotor blade.

  - mill and transport “dry” soils using a jet of air (fig. 4);

  fig. 3. Detachable body multi-function device.

- due to the installation of the teeth on the lower movable part of the body: 3.1. work as a clamp grapple to remove garbage from water reservoirs (ponds).

Opposite rotating parts of the rotor have cutting edges which are formed by H-shaped cut contour on the rotor blades. They grind up all kinds of crop to the size to ensure its passage between the rotor blades. Later this crop is removed along with the soil during the next operation.
Extract "dry" soils using a jet of air.

The lower half of body is transferred to the upper position and fixed releasing cutting edges of the rotor blades. As the rotor rotates, the ground is cut by end edges, shifted to the working surface of the blades, dispersed and ejected through the exhaust window to the desired distance from the channel.

- - pump water;

To perform this function the lower part of the body is transferred to the lower position, forming inner working volume of enclosure, its outlet is equipped with a pressure pipe (servo drive or manually) and the inlet – with a suction nozzle [3, 4, 5], (fig. 5).

As the rotor turns water in the working volume of the body is dispersed by the blades in the circumferential direction and due to centrifugal acceleration it rushes to the periphery, creating excessive pressure. Due to the pressure difference in the periphery of the body and in the pressure pipe outlet water (or water-soil mixture) is removed through the outlet and pipe from the enclosure at a desired distance (fig. 5). In the central part of the body a vacuum is formed, and the new amount of water is supplied from outside through the suction nozzle.

fig. 4. Multi-function device configured to work in underwater conditions

fig. 5. Multi-function device configured to work in underwater conditions

fig. 6. Removal of water from household wooden

Spiral casing design with permanently installed pipe line is designed, manufactured and tested to reduce the difficulties for installation and removal of pipe, and to improve efficiency when operating as a pump[6], (Fig. 7).

fig. 7. Multi-function device with spiral casing and permanently installed pipeline

Testing the given device proved expediency of its use. Nozzles change their functions by opening-closing the propellant tube.

- - extract and transport the soil from under the water (fig.8);
Experience has shown that under free water intake alluvial soils are not destroyed if to clean channels using the device discussed above. To intensify the cleaning of flooded channels, a combined hydro-loosening system in the form of two alternately working nozzles (fig. 9) which are controlled by a hydraulic drive of the base machine is mounted on the movable and detachable part of the body (housing).

Moreover, the pipes are installed in the abnormal portion of the body where the rate of water flow outpaces the circumferential velocity of the peripheral portion of the rotor and, therefore, the pressure on the loosening jets (20m) exceeds the pressure in the discharge line and is sufficient for loosening the soil.

Regime of shift work of nozzles is done by electronic hydrodistributor. This provides a highly efficient destruction of dense soil, bringing consistency of water soil mixture up to 40%.

Version of multifunctional working device with a vertical orientation of the axis of rotation is also designed, manufactured and tested, thus eliminating the suction pipe (nozzle) and mechanizing the process of changeover.

- due to the installation of the teeth on the lower movable part of the body (Fig.10):

- as a clutch grapple to remove garbage from water reservoirs (ponds).

Unitization of this working body with rotary-screw propulsor (RSP) [7, 8, 9] makes its use in the intracanal version even more versatile since in addition to the obvious advantages of the RSP in working on liquid soils and its high maneuverability, it will be used for cutting soil.

3. Conclusion
The basis of multifunctionality of this invention is in the principle of implementation of the maximum number of hidden abilities of the initial technical system, its rotor, manipulator parts. This is consistent with the laws of development of technical systems and in the long term implies the creation of industrial ground robots that adapt to the technological requirements and various soil conditions. Creation of a reclamation robot will allow to complete the entire cycle of canal cleaning works daily, including weekends and holidays at maximum capacity, with only partial participation of an operator.

The device has been tested in the Nikolayev region of Ukraine and in the Nizhny Novgorod region of Russia.

4. Literature
2. Useful model patent №129492 RU, B65G31/04. Rotary thrower / E. G. Ivanov, V. N. Novichkov, P. V. Pchelnikov. – stated 05.02.13; published 27.06.13.
Commonly prevailing trend in the food industry is a decrease of technological processes costs with simultaneous increase of demands in terms of quality and food articles safety [11]. This forces a continuous search of a new food processing methods and constitutes a driving factor for novel food processing methods forming, including those connected with food pasteurization and sterilization, among others.

Sterilization is one of the basic thermal treatment process employed in foodstuff processing. Mainly, it is based on a very intense heating treatment of a product. The process temperature ranges vary from +115 to +121°C or +130 to +145°C. The aim of the sterilization process is an eradication of all microorganisms and its endospores forms [15].

Food products in a solid or semiliquid state are subjected to sterilization or pasteurization in a tunnel- (fig. 1) or tank- (fig. 2) construction devices [10].

Development of new technologies, respecting pasteurization and sterilization, is targeted at acceleration of food processing technology together with decreased energetic input. The most significant progress, in this respect, has been made in terms of technical solutions of tank sterilizers. Study of different constructional and technological variants in the range of tank sterilizers solutions is performed in four main areas (fig. 3).
A tank sterilizer is a hermetically closed container used for thermal treatment of food. Thanks to its structure, it is possible to reach a significant pressure values in the working chamber (usually 2 – 4 bar), thus enabling the decrease of operating temperature. By increasing the values of physical parameters of a running process, a significant reduce of time may be achieved [1, 3].

The second important area is the selection of an appropriate heating medium. In tank-type sterilizers hot water or water vapor spraying is widely used. Use of the water vapor as a heating medium may be a very beneficial solution. Saturated steam has higher specific enthalpy by an order of magnitude comparing to water for the same physical parameters. For comparison, at pressure 2,5 bar and temperature app. 125°C the specific enthalpy for water reaches 525 kJ•kg⁻¹, whereas for vapor being under saturation, for the same pressure is equal to 2733 kJ•kg⁻¹ (computed according to [9]). Nevertheless the usage of vapor as a heating medium brings some restrictions as well. The main limit is connected with costs and exploitation of a vapor transporting infrastructure and connection armature.

Another important area is a selection of adequate thermal insulation. In the vast majority of sterilizers insulation, a special wool, placed on the operating chamber casing and covered by sheet metal is used as an insulation. Though spraying with ceramic materials onto surfaces is being increasingly used. Selection of a suitable insulation material, layer thickness and arrangement is of primary importance for heat loss to the surroundings [1, 2, 3].

The last area of selection is the relative motion of a batch. Leading European sterilizers manufacturers have in their offer at least two solutions of the internal system. The former is a stationary system in which a basket, containing a batch, located on a trolley is pushed onto an operating chamber chain conveyor (in a shorter versions of sterilizers roller conveyor is extensively used). Then, through chain drive launch, basket is transported to the chamber interior in a manner which allow to transport remaining baskets (fig. 4). Unloading action is performed analogously.

The sterilization process is based on spraying a heating medium (water or water vapor) onto baskets which are arranged on conveyor. Spraying can be performed gravitationally or can be forced. In the former one, a collector is located close to the upper surface of the tank. Water flows onto a so called head shower which has many holes thanks to which water is evenly distributed onto a batch. System with forced flux consists of group of pipelines with nozzles, altogether attached to the working chamber casing. Heating medium flows through pipes under high pressure, and is distributed onto baskets from different directions [1, 3]. In both situations, any movement of a batch relative to tank occurs, what in case of sterilization of liquid or semi-liquid products is a serious technological limitation.

The movement within a product during sterilization brings a number of advantages, the most important of them involves [1, 3]:
- increase of values of heat transfer coefficient (forced convection),
- mixing and homogenization of products (particularly desirable in semi-liquid products),
- decrease of processing time,
- decrease in heat and electric energy consumption.

With a view to above-mentioned benefits, a number of producers have developed systems enabled to move a loading relatively to the sterilizer working chamber. Among the design solutions of an internal swaying systems, two basic types can be distinguished: rotational (oscillatory motion) and reciprocating.

The rotational system consists of a special construction frame, being an assembly of rings connected together with profiles which are fixed radially with respect to tank horizontal axis. Loading and unloading process of baskets is performed through chain or roller conveyor. In the Steriflow SAS (Barriguand) solution, the outer layer of a first ring works as a track for roller units, which are fixed to the sterilizer tank. Drive is transferred from a gearmotor through shaft which enters the working chamber from tank end side (fig. 5).
During operation the construction is moved with adequate angle performing an oscillatory movement with velocity ranging from 2 to 20 rev/minute. Application of an additional, multipoint heating medium injection ensures very good conditions for heat exchange [8, 12].

Similar solution is employed by Gea Levat Food Tech S.r.l. Baskets are also fixed in a special construction frame being an assembly of rings connected together by profiles. However, here, unlike to sterilizer from Steriflow SAS, an annular gear is used fixed to the outer layer of frame ring and works with gear wheels driven by motorgear (fig. 6).

The system from Gea Levati Food Tech is enabled to perform a full rotation of a batch about the tank horizontal axis. The use of annular gear working together with gear wheels facilitates precision control [14].

The main disadvantage of described solutions is the frame, which significantly reduces the working space of a sterilizer.

With this in mind a Spain company Surdry S.L. has developed their own oscillatory construction based on chain conveyor which is placed on a special construction bed. Driving unit sets in motion the conveyor together with baskets (fig. 7).
The main advantages of the oscillatory system employed by Surdry S.L. are: large volume of the working chamber, simple construction and a wide range of working parameters. Due to the system working condition it is addressed to products placed on trays (fishes and meat in airtight packages) and in unit packages like doypack, which in sum is a major limitation [4].

Second type of sterilization-aided systems are reciprocating motion systems. The simplest one is system called “DALI” developed by Steriflow SAS company. Operation of the system is based on conveyor chain control, on which baskets are fixed. The reciprocating motion amplitude is relatively large because it can reach even several hundred millimeters. Whereas its frequency is small due to the electric motor limitations related with cyclic changes of rotation direction [8].

The system is characterized by simplicity. One major advantage is that the sterilizer has large working chamber. However, low frequency do not intensifies heat exchange as good as the competitive systems.

The most technically advanced system with reciprocating motion is “SHAKA” developed by Steriflow SAS. Similarly with “DALI” system, baskets perform reciprocating motion but the driving motorgear is connected with a crank mechanism. This mechanism is fixed to the baskets fixing construction which lies on slideways. The system motion is characterized by relatively large amplitude (about 150 mm) and rotation velocity reaching 100 – 200 rev./min (fig. 9). High mixing parameters as well as heat transfer coefficients allow to decrease sterilization time [8, 13].
Despite a number of advantages of the „SHAKA” system, there exist some disadvantages related to its use. The main drawback of the system is its lack of universality, i.e. it is dedicated to a sterilization of narrow range of liquid products or semi-liquid products in precisely selected unit packages (fig. 10).

Wide range of rotation velocity values of the system forces a use of baskets having appropriate construction, closely fitted to sizes and amount of unit packages with product. Any change in packages parameters is associated with the need to rebuild current baskets or their total replacement. Hence above solution is beneficial for those food producers who produce large series of the same product.

**Summary**

Sterilization process of food products plays a significant role in the food industry. Continuous pursuit of food manufacturers to reduce the costs of food production with simultaneous increase in its safety and quality makes that sterilizer producers develop technologies that meet the expectations of food sector producers. The essence of these technologies is intensification of heat exchange processes which aim is decrease of processing time and thereby decrease of costs. Technical solutions are focused on four main areas, namely: change of a process physical parameters, choose of an adequate heating medium and insulation material, and finally on relative motion of a batch.

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**Literature**