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KINEMATIC ANALYSIS OF THE WORKING PROCESS OF TRENCHER

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Summary. The kinematic analysis was performed of works unearthing the pipeline along its perimeter. The relationship was established between kinematic and geometric parameters of the working equipment.

Key words: kinematic analysis, trencher, **pipeline, parameters**

INTRODUCTION

Reliability of pipelines in Ukraine is very important as it affects the degree of stability of the Western European countries fuel and energy resources. Given that the present system of pipelines was most actively under construction in 1960...80 years, most of them have operated with significant excess of useful life. This fact results in a reduced operational reliability of pipelines, which largely depends on a timely and quality repair.

The operational reliability of pipelines is significantly affected by corrosion coating, arising from an intensive process of ageing. This usually leads to frequent accidents and stops pumping oil to consumers.

New technology overhaul includes recovery line without lifting pipe from the trench along the length of the repaired area [1]. This repair is performed through the use of technology involving special earthmoving machines (Fig. 1). One of them is trencher, which is used for the digging of the pipeline trench. The authors suggested adapted working equipment, which allows to fully disclose the pipeline on its perimeter without the use of machine digging under the pipe. Modernization of the machine requiring adequate scientific study of construction and kinematic parameters of the working equipment as well as thorough consideration of the related problems is important.

The aim of the research was to perform the kinematic analysis of the working process of a trencher machine during the unearthing of a pipeline without digging under the pipe.

THE MAIN RESULTS

The authors proposed the construction of a trencher (fig. 2) consisting of the base machine *1*, which is moved along the pipeline *2* and working equipment *3* [2]. Ground is destroyed and transported by sections of chain *4, 5*. Then the ground is moved in the conveyor *6*. Equipment is controlled by hydraulic cylinders *7, 8, 9*. Movement of the machine base along the route of the pipeline construction is controlled by device *10*.

After turning on the pipeline trencher with two chain sections, the workflow is a combination of the following movements: motion of chain at fixed cutting tool speed v_c; motion of machine base along the pipeline track and trench digging at speed v_M.

Thus, the cutting tool performs a complex motion: along the chain it moves onto the car and together with the machine - with respect to ground [3].

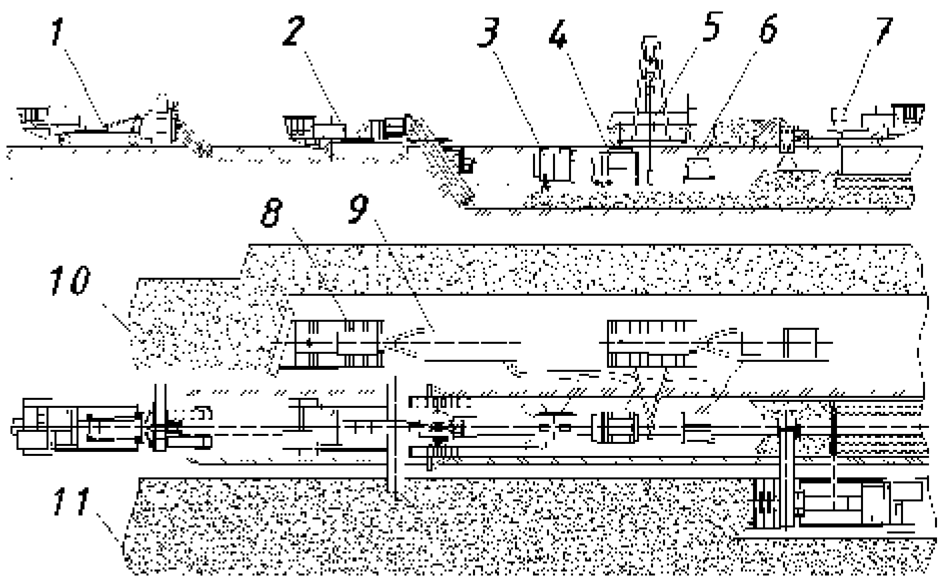

Fig. 1. Technology repair pipelines: 1 – machine digging the soil layer; 2 – machine unerthing pipeline; 3 – machine digging soil pipeline; 4 – machine removing isolation; 5 – pipeline compiler; 6 – machine causing isolation; 7 – machine for soil compaction; 8 – bulldozer; 9 – diesel power; 10 – fertile ground; 11 – mineral soil

1. Consider the kinematics of motion of working equipment machine-prototype, installed in parallel to each other chain sections (without digging under the pipe).

When working at unearthing the underground pipeline parallel to each other chain sections machine operate on a longitudinal excavator digging when the motion of the chains of working equipment is on the same plane (or parallel) with the movement of the machine base.

Kinematic feature is the deviation of the trajectory of the cutting tool at an angle (Fig. 3, 4), which is smaller than the angle of frame work equipment to the ground β:

$$[4]: \operatorname{tg}\alpha = \frac{v_c \sin\beta}{v_c \cos\beta + v_M}.$$

Analysis of this dependence shows that the trajectory angle of cutting mainly depends on the angle frame work installation of equipment and chain speed because the speed of machine's movement is a relatively low.

As the chain sections are set at different angles to the bottom of the soil for overlapping axis of the trench while digging under the pipe (see Fig. 2), respectively angle cutting tool paths for each section will be different [5]. Let the angle β_1 to the bottom for one section (eg, right), usually it is about 60°.

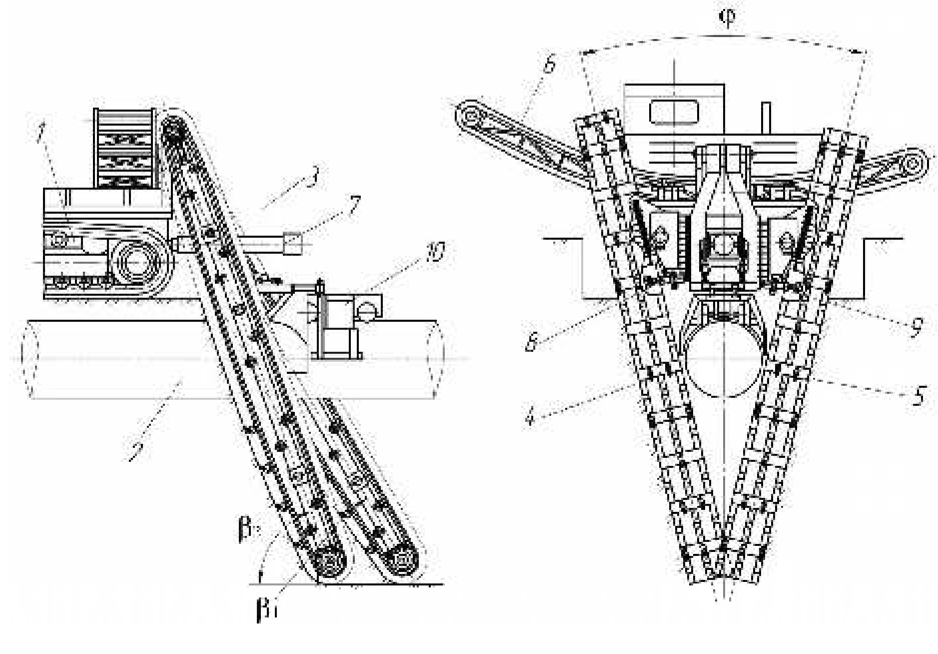

Fig. 2. Chain trencher: 1 – basic machine; 2 – pipeline; 3 – working equipment; 4,5 – chain section; 6 – conveyor; 7...9 – hydraulic cylinders; 10 – control devices

And with this in mind, rejecting the path of the cutting tool for the right sections will be $\mathrm{tg}\,\alpha_1 = \frac{v_{c1}\sin\beta_1}{v_{c1}\cos\beta_1 + v_M}$, where v_{c1} – speed circuit right section of the working equipment; v_M – speed of machine base, and $\alpha_1 = \mathrm{arctg}\frac{v_{c1}\sin\beta_1}{v_{c1}\cos\beta_1 + v_M}$.

To the left section, taking into account the fact that it is set at an angle β_2 will be

$$\mathrm{tg}\,\alpha_2 = \frac{v_{c2}\sin\beta_2}{v_{c2}\cos\beta_2 + v_M}, \text{ or } \alpha_2 = \mathrm{arctg}\frac{v_{c2}\sin\beta_2}{v_{c2}\cos\beta_2 + v_M},$$

where: v_{c2} – speed circuit of the left section of working equipment.

These formulas connect the speed of machine base v_M and kinematic parameters of movement of relevant sections of chain.

The parameters of the layer that is removed during the work of the cutting tool of a machine is its width and thickness. The width of the layer depends on the geometrical parameters of the working body, so its value is calculated as host based on the working parameters of the body.

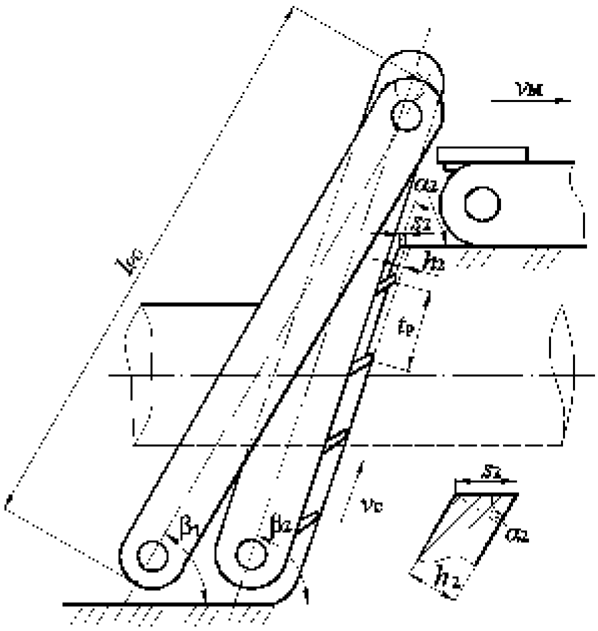

Fig. 3. Traffic patterns of the cutting tool chain sections of the working equipment

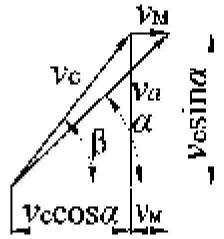

Fig. 4. Graph of equipment speed for the parallel sections

Taking into account the kinematic parameters of the machine (see Fig. 3), the thickness of the layer h_2 for the left section of the working body $h_2 = s_2 \sin \alpha_2$, where s_2 – the moving forward cutting tool for the left section. Similarly, determine the thickness of the layer h_1 for the right section of the working body : $h_1 = s_1 \sin \alpha_1$, where s_1 – the moving forward cutting tool for the right section.

Given that the basic machine speed compared to speed of the chain is of low value, ie $v_1 << v_c$, you can assume that angles $\beta \approx \alpha$, ie cutting speed corresponds approximately to the ground speed of the chain corresponding to sections of working body. Therefore, we can write $h_1 = s_1 \sin\beta_1$, $h_2 = s_2 \sin\beta_2$.

The forward movement of cutting tool for the left and right sections will be $s_1 = t_p \frac{v_M}{v_{C1}}$, $s_2 = t_p \frac{v_M}{v_{C2}}$, where t_p – step placement incisors in line cutting. Given these formulas, the thickness of the layer $h_1 = t_p \frac{v_M}{v_{C1}} \sin\beta_1$, $h_2 = t_p \frac{v_M}{v_{C2}} \sin\beta_2$.

Analyzing the last formula one can conclude that changing the parameters of motion of the base machine v_M and chain v_C it is possible to adjust the thickness of the layer h to constant constructive and kinematic parameters of the work equipment t_p i β. For a smooth adjustment of values v_M and v_C it is necessary to apply an adjustable hydraulic, because manual transmission, even with a significant number of gears allows for discrete changes in these parameters.

Thus, the values can be determined of the speed of chain sections and parameters of the ground layer at the parallel chain sections.

2. Consider now the movement kinematics of working equipment for digging under the pipeline, i.e. when the chain sections are set to each other at an acute angle φ (Fig. 5). This kinematic process changes affect the progress of machines in general.

Absolute velocity vector v_a equation of the form (see Fig. 5) $\bar{v}_a = \bar{v}_C + \bar{v}_M$, where $\bar{v}_C$ – the velocity vector of the chain corresponding to sections of working body; v_M – velocity moving the machine base in the development trenches.

For example, consider the kinematics of movement of left chain sections working body. We have the spatial (three dimensional) coordinate system with coordinate axes *x*, *y*, *z*, point *0* – the origin. Speed chain v_C (and hence the plane of motion) will deviate from the plane of movement of the machine base on the corner $\varphi/2$, which provides for overlapping axis of the trench bottom of the working body sections. Velocity v_C is directed at an angle β to the plane *xz*, which equals the angle of the frame installation sections of chain working body.

Plane velocity of machine's vector v_M is parallel to the plane (axis) motion of the tractor *yz*. So, get the absolute cutting speed ground v_a. Vector v_a is on the plane that deviates from the plane of motion of the tractor at an angle γ which is at an angle θ to the horizontal plane *xz* (bottom plane).

Determine the parameters v_a, θ, γ, for which consider the triangle ΔOAB, in which the parties $OA = v_C$, $AB = v_M$, with the angle between them $\psi = 180^0 - \varphi/2$. According to the law of cosines $v_a = \sqrt{v_C^2 + v_M^2 - 2 v_C v_M \cos\left(180^0 - \varphi/2\right)}$. In triangle ΔBDO: $\sin\theta = \frac{BD}{OB}$, where $BD = AC = OA\sin\beta$.

Whereas $OB = v_a$, $OA = v_C$, get $\sin\theta = \frac{v_a}{v_C \sin\beta}$, or

$$\theta = \arcsin\frac{\sqrt{v_C^2 + v_M^2 - 2 v_C v_M \cos\left(180^0 - \varphi/2\right)}}{v_C \sin\beta}.$$

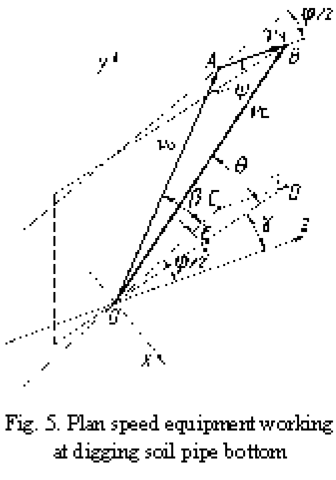

Fig. 5. Plan speed equipment working at digging soil pipe bottom

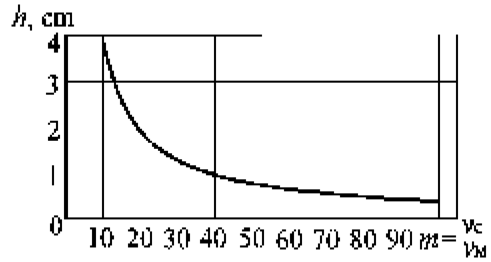

Fig. 6. Dependence of thicksness of layer from the structurally-kinematic parameters of the process

The dependence can be determined of the parameters of the working body speed ν_C, the machine base ν_M angles and setting of the frame of chain sections in the horizontal plane β and slope $\varphi/2$ for digging soil pipe bottom.

Angle γ of the plane of the absolute speed ν_a of the plane motion of the tractor yz is presented in Fig. 5 $\gamma \;\; \varphi/2 \;\; \xi$, where ξ – the angle between the horizontal projections of the absolute cutting speed ν_a and speed chain ν_C. In the triangle: ΔCOD: side $OC = OA\cos\beta$, $OD = OB\cos\theta$, $CD = AB = \nu_M$.

Replacing the sides of the triangle ΔCOD through the horizontal projection speeds gets:

$$\cos\xi = \frac{\nu_M{}^2 - \nu_a{}^2\cos^2\theta - \nu_C{}^2\cos^2\beta}{2\nu_C\cos\beta\,\nu_a\cos\theta}, \text{ or } \xi = \arccos\frac{\nu_M{}^2 - \nu_a{}^2\cos^2\theta - \nu_C{}^2\cos^2\beta}{2\nu_C\cos\beta\,\nu_a\cos\theta}.$$

Then angle $\gamma = \varphi/2 - \arccos\dfrac{\nu_M{}^2 - \nu_a{}^2\cos^2\theta - \nu_C{}^2\cos^2\beta}{2\nu_C\cos\beta\,\nu_a\cos\theta}$.

The last formula implies that the layer thickness of soil at the digging under the pipeline has the form $h_1 = t_p\dfrac{\nu_M}{\nu_{C1}}\sin\theta_1$, $h_2 = t_p\dfrac{\nu_M}{\nu_{C2}}\sin\theta_2$. Speed circuit trench excavator is usually ν_C 0,4...2m/s, and speed machines in the unearthing of the pipeline is ν_M = 80 m/h (ν_M = 0,022 m/s). The graph in Fig. 6 shows the dependence of the thickness of the ground layer on the construction (cutting tool step's location, angle's setting frame) and kinematic (speed chain and machine) parameters of the process.

According to the graphic interpretation of the specified formulas, with higher speed chain at a constant speed machine, the thickness of soil layer decreases. The ratio of the observed rapid reduction of layer ground thickness is $m = \dfrac{\nu_C}{\nu_M} = 10...50$, while the velocity ratio m = 60...100 is not a substantial change of parameter h. Therefore, in this range the change of chain speed is irrelevant.

CONCLUSIONS

As a result of tests, kinematic analysis during the work of the machine established that the trajectory of the cutting tool α deviates from the angle of the sections β of working equipment.

This dependence, which is associated with geometric and kinematic parameters of the process of digging the soil, namely: the thickness of the ground layer h, angle of inclination of sections to cut ξ, γ, φ, location of the cutting tool's step t_a etc.

Based on the dependencies you can define and regulate the speed of the chain ν_C and machines ν_M to provide the necessary thickness of the ground layer h.

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ANALIZA KINEMATYCZNA PRACY KOPARKI DO ROWÓW

Streszczenie. Przeprowadzono analizę kinematyczną prac przy odkopywaniu rurociągu wzdłuż jego obwodu. Ustalono relację pomiędzy parametrami kinematycznymi a geometrycznymi pracującej maszyny.

Słowa kluczowe: analiza kinematyczna, koparka do rowów, rurociąg, parametry