Trencher equipment

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Abstract. The article reflects the results of theoretical studies aimed at improving the equipment of the chain trencher. The proposed design allows the development of trenches on the sides of the pipeline. In addition, with the help of a cutter drum equipped with a rotary mechanism, the equipment removes soil from under the repaired pipe section. To confirm the health of the proposed technical solution, calculations were made of the power of consumption on the drive chain of the work equipment and cutter drum. When developing the design, calculations were made to determine the diameter of the shaft and check the splined joint for crumpling.

1 Introduction

The main development of the pipeline transport system of the Russian Federation was in the 70-80 years of the XX century. To date, depreciation of its fixed assets is more than 50%, which leads to forced stops in the transport of oil or another product, which reduces technical productivity [1,2]. So, for example, in the gas transmission system of 154 thousand km of gas pipelines 60% of the pipes have been used for 10 to 30 years, and the insulation period protecting the pipeline from corrosion is no more than 15 years [3]. All this against the background of long-term operation of pipelines, their wear and tear has determined the need to carry out large volumes of repair of the pipeline system for pumping hydrocarbons[4].

A factor that inhibits the improvement of the repair of linear parts of pipelines is the imperfection of the technique of the earthworks performed. Although, this type of work is in great demand in the Russian Federation. This is due to the long-term operation and 50% percent deterioration of the pipeline transport system, quite developed in the country [5].

A review of the existing designs of trenchers designed for opening pipelines allowed us to conclude that the lack of versatility of these machines and the need to create dual excavator implement. The equipment will be a combination of chain-type equipment with a change in the angle of inclination and a copying tool, as well as a cutter drum, to destroy the ground under the pipe.

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2 Researching

Overhaul of the main gas pipeline is a set of technical measures, aimed at the full or partial restoration of the linear part of the operated gas pipeline to design characteristics, taking into account the requirements of current regulatory documents. Overhaul of gas pipelines, as a rule, should be carried out after the elimination of dangerous defects identified as a result of diagnosis [6].

During overhaul with the replacement of pipes by dismantling the replaced pipeline and laying a new one in the previous design position, technological operations are performed in two stages [6, 7].

At the first stage, work is performed in the following sequence: clarification of the position of the replaced pipeline; removing the fertile soil layer, moving it to a temporary dump; opening the pipeline to the lower generatrix; pipeline shutdown; emptying, flushing the replaced pipeline; lifting, cleaning of the old insulating coating and laying the pipeline on the edge of the trench; cutting the pipeline into parts; transportation of pipes to the place of storage [3,8].

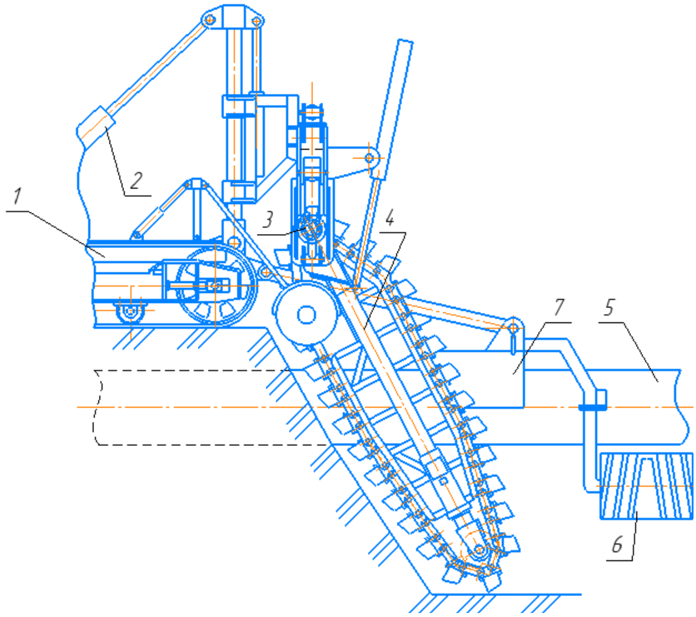
At the second stage, work is performed in the following sequence: refinement or development of the trench; removal of sections on the track and their layout on the edge of the trench; welding sections of pipes into a thread; cleaning, applying insulation coating; laying the pipeline in a trench; dusting of the pipeline and backfilling of the trench with mineral soil; cleaning the internal cavity of the pipeline; test for strength and tightness; connection of electrochemical protection; connection (insert) of a new section to an existing oil pipeline; technical reclamation of the fertile soil layer[5,7].

In order to reduce time costs and increase productivity of excavation during the overhaul of the pipeline, the task was set to improve the design of the equipment of the trencher. Analysis of existing structures and patent research showed that machines working from the surface of the earth are bulky and metal-intensive, as the excavation is carried out at a greater depth, therefore, it is necessary to conduct soil development closer to the surface of the pipeline [9].

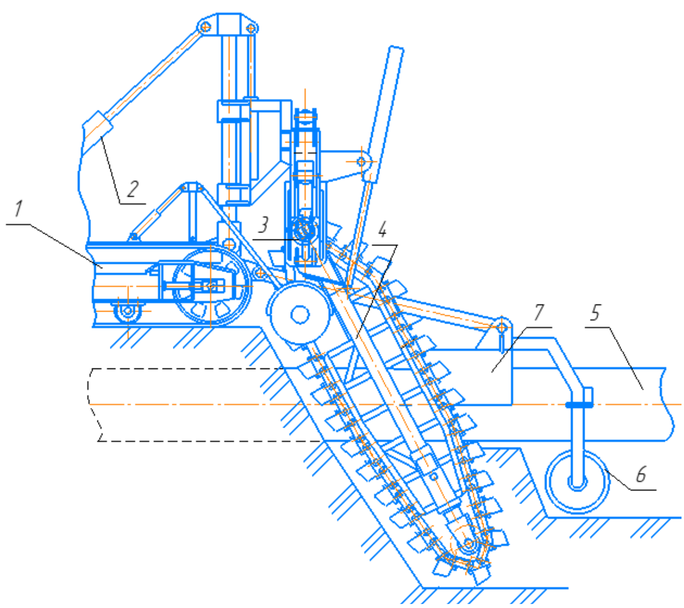
This allows us to draw the following conclusions:

1. It is necessary to create dual excavator implement.
2. More preferred is chain-type equipment with a change in the angle of inclination relative to the axis of the pipeline.
3. It is advisable to use a commercially available tractor unit as a base.
4. It is necessary to use a hydroficated drive of equipment.
5. In order to improve the quality of work performed, it is necessary to create a copying tool for cleaning the soil on the upper part of the pipeline.

Therefore, the authors of this article proposed the design of the equipment of the trencher, presented in Figure 1.



a



b

Fig. 1. Modernized equipment of the trencher: a – neutral position of the cutter drum; b –working position of the cutter drum

The proposed version of the design is:

1 – base machine; 2 – device control the position of the chain equipment; 3 – drive chain equipment; 4 – chain equipment; 5 – pipeline; 6 **-** mill cutter; 7 – copying tool [9].

Designed earthmoving machine allows for one pass to perform work on the opening of the pipeline, by developing 2 parallel trenches at a given distance from the axis of the pipeline and removing the soil below the lower repaired section of the pipeline section. This will avoid attracting humans to remove the soil manually [9].

3 Theoretical studies of the proposed design of equipment

During the research, a trench trencher (TCE 1616) was taken as the object of study. The choice of a machine is connected with the fact that this model is widespread during repair work of trunk pipelines for soil development of categories I ... III. The excavator is used to open pipelines with a diameter of 520 ... 720 mm for subsequent repair of the pipeline [10].

Theoretical studies were carried out for three categories of soils, differing in the coefficient of specific resistance to digging (k_1). For soils of the first category k_1 amounted to 150.000 N/m^2, for soils of the second category k_1 amounted to 300.000 N/m^2, for soils of the third category k_1 the value 450.000 N/m^2 was adopted [11].

A hydraulic drive is used in the TCE 1616, therefore, it is advisable to use stepless speed control of the drive shaft of the equipment. Previous studies have identified a range of working speeds of the chain, which is equal to 0.83-2.14 m/s.

The required speed of the drive shaft of the working circuit is determined by the formula [12]

$$n = \frac{V_c \cdot 60 \cdot 1000}{z \cdot t}, \quad (1)$$

where V_c – speed of the equipment, V_c = 0.83-2.14 m/s; z – leading sprocket teeth number, z =8; t – pitch working chain, t = 100 mm.

The calculation made it possible to determine the interval of the rotational rotation frequency of the drive shaft, which turned out to be equal to n = 62-161 rpm.

The rotation frequency auger is determined by the formula [12]

$$n_a = n \frac{z}{z_a}, \quad (2)$$

where z – leading sprocket teeth number, z =8; z_a – driven sprocket teeth number, z_a=6.

Thus, the rotation frequency auger is determined in the range n_a= 47-121 rpm.

Trencher productivity according to the excavated volume of equipment is determined by formula [13]:

$$P_T^c = 2 \cdot 3600 \cdot b \cdot h_c \cdot V_c \cdot \frac{\kappa_t}{\kappa_p}, \quad (3)$$

where b – width of the bucket, b =0.8 m; h_c – bucket height, h_c=0.16 m; κ_t – bucket conveying coefficient, κ_t = 0.8; κ_p – soil loosening coefficient, κ_p=1.15-1.25.

Trencher productivity limited by auger extension capacity is determined by the formula [13]

$$P_T^a = 2 \cdot \frac{\pi(D^2 - d^2)}{4} \cdot S \cdot n_a \cdot 60 \cdot \psi, \quad (4)$$

where D – outer diameter of the auger, D =0.500 m; d – diameter of the shaft auger, d =0.072 m; S – pitch of the screw, S =0.3 m; ψ – coefficient of filling of the auger, ψ =0.4.
Productivity limited by working speed is determined by formula

$$P_T = V \cdot S_t, \quad (5)$$

where V – working speed, m/h; S_t – cross-sectional area of the trench, m2.

For soil developed by chains:

$$S_{t1} = b_1 \cdot H_1 \cdot 2. \quad (6)$$

For soil, under pipe space:

$$S_{t2} = b_2 \cdot H_2. \tag{7}$$

where H_i – depth of the trench.

To conduct theoretical research, it was necessary to determine the power required to drive the chain of equipment, reduced to the motor shaft. The calculation was performed according to the formula [12]

$$N_{po}^{d} = \frac{N_k + N_p}{\eta_p + \eta_c}, \tag{8}$$

where N_k– power spent on digging the ground, kW, N_p – power spent on lifting soil, kW, η_p – efficiency of the chain drive; η_c – efficiency of productivity of the bucket freely sagging chain, η_c =0,6.

$$N_k = \frac{\kappa_1 \cdot P_T}{367 \cdot 10^4}, \tag{9}$$

where κ_1 – specific resistance to digging, N/m^2; P_T – productivity of the trencher, m^3/h [14].

Power used to lift the ground (N_p) is determined by formula

$$N_p = \frac{P_T \cdot \gamma \cdot \left(\frac{H}{2} + H_0\right) \cdot (1 + f_1 \cdot \mathrm{ctg}\beta)}{367 \cdot 10^4}, \tag{10}$$

where γ – bulk density of the ground, $\gamma \approx 17000$ N/m^3; H – the depth of the trench, m; H_0 – the height of the soil from the ground to the unloading point, m; $H_0 \approx 1$ m; f_1 – coefficient of soil friction on the ground, f_1 = 0.8; β– angle of inclination of the face surface to the horizon.

The efficiency of the equipment (η_p) is calculated by the formula

$$\eta_p = \eta_r^5 \cdot \eta_m^2, \tag{11}$$

where η_r – efficiency of the planetary gearbox, η_r = 0.96; η_m – efficiency of the gear clutch, η_m= 0.99.

The power required to drive the auger, reduced to the motor shaft, is determined by the formula [15]

$$N_a^d = \frac{\gamma \cdot P_a \cdot L}{3670000 \cdot \eta_a \cdot \eta_{ad}}, \tag{12}$$

where L – total length of the left and right augers, L =1.50 m; P_a –auger productivity; γ – volume weight of the ground, $\gamma \approx 17000$ N/m^3; η_a – efficiency of the auger, η_a=0.6; η_{ad} – efficiency of the auger drive.

The efficiency of the auger drive can be found by the formula

$$\eta_{ad} = \eta_p \cdot \eta_{cd}, \tag{13}$$

where η_p – efficiency of the drive chain of the equipment, η_p=0.85; η_{cd} – chain drive efficiency, η_{cd}=0.9.

The power required to drive the drum is determined by the formula [15]:

$$N_d^d = \frac{N_k + N_m}{\eta_p}, \tag{14}$$

where N_k – power spent on digging the ground, kW; N_m – power spent on moving the ground to the side, kW; η_p – efficiency of the drive chain of the equipment.

$$N_k = \frac{k_1 \cdot P_T}{367 \cdot 10^4}. \tag{15}$$

$$\eta_p = \eta_g \cdot \eta_m \cdot \eta_h \,, \tag{16}$$

where η_g – efficiency of the hydraulic motor, , η_g =0.85; η_m – efficiency of the gear clutch, η_m=0.99; η_h – efficiency of the splined joint, η_h=0.96.

The power spent on moving the ground to the side (N_m) was determined by the formula

$$N_m = \frac{\gamma \cdot P_a \cdot l}{36700000 \cdot \eta_d} \,, \tag{17}$$

where l – length of the drum, l =1 m; P_a – auger productivity; γ – bulk density of the ground, $\gamma \approx 17000$ N/m^3; η_d – drum efficiency, adopted, $\eta_d = \eta_h$ =0.6.

When conducting research, it was assumed that the drum shaft is made of material Style 45, improvement, HB = 207 ... 236. The permissible stress of such a material is [σ] u = 60 MPa, and the strength limit σв=780 MPa [16]. The length of the drum shaft is 400 mm.

The diameter of the drum shaft is calculated by the formula [3,14]

$$d_{sd} = 10\sqrt[3]{\frac{10T}{[\sigma]_u}} \,, \tag{18}$$

where T – rated torque of the hydraulic motor shaft; [σ]u – permissible bending stress for the material, [σ]u =60 MPa.

Given the weakening of the shaft in the calculated cross section by slotted grooves, during theoretical studies, the diameter was increased by 10% [3,4].

Checking the splined connection for crushing is performed according to the formula

$$\sigma_s \approx \frac{T}{0.75 \cdot r \cdot A_s \cdot R_s} \leq [\sigma]_s \,, \tag{19}$$

where r – number of splines; R_s – effort to collapse; $[\sigma]_s$ – permissible stress on collapse; A_s – calculated crushing surface is determined by the formula

$$A_s = \left(\frac{D_{hc} - d_{hc}}{2} - 2f\right) \cdot v \,, \tag{20}$$

where v – length of the hub; D_{hc}– nominal diameter of the output shaft of the cutter drum hydraulic motor; d_{ch} – nominal diameter of the circumference of the hollows of the shaft of the hydraulic motor of the cutter drum.

$$R_s = 0.25 \cdot (D_{hc} - d_{ch}). \tag{21}$$

Studies have shown that for this compound, the permissible bending stress of the selected material is $[\sigma]_s$ =40MPa. This indicates that the slots withstand the transmitted moment [6,12].

4 Research results

As a result of the studies, graphical dependencies were obtained that reflect the definition of the trencher's productivity by the chain carrying capacity, auger carrying capacity and productivity limited by the acceptable speeds of the machine's working mode [1,17].

As an example, Figure 1 graphically shows the dependence of the productivity of the trencher, according to the carrying capacity of the chain, depending on the category ground.

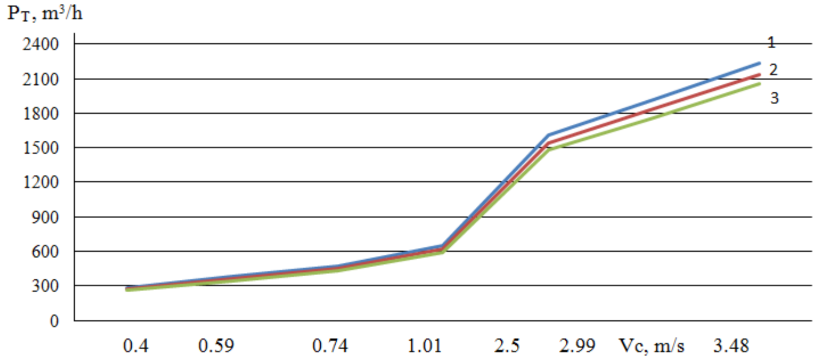


Fig. 2. Trencher productivity relationship from soil category: 1 – ground of the first category; 2 – ground of the second category; 3 – ground of the third category.

The difference in machine productivity during the development of category 1-3 ground s is insignificant and varies in the range of 2000 - 2250 m^3/h.

Table 1 presents the results of determining the maximum productivity of the trencher at different working speeds, taking into account the depth of the trench and its cross-sectional area.

Table 1. Maximum trencher productivity.

H, m	S, m^2	V, m/h							
		450	590	740	1010	2510	2990	3480	4140
2.12	3.8	1710	2242	2812	3838	9538	11362	13224	15732
0.84	0.61	275	360	452	616	1532	1824	2123	2526

As a result of the studies, graphical dependencies were obtained that reflect the effect of the required power on the drive circuit of the equipment, on the auger drive and the drum drive on the machine productivity, taking into account the category of developed ground [9].

Also, as an example, the results of theoretical studies, Figure 3 presents graphical dependences of the influence of power consumption on the cutter drum drive, depending on the productivity of the machine.

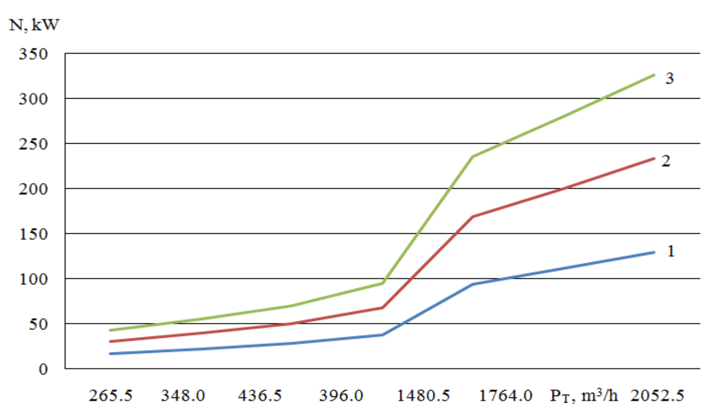


Fig. 3. Dependence of power consumption on the cutter drum drive from trencher productivity: 1 - ground of the first category; 2- ground of the second category; 3 - ground of the third category.

5 Conclusion

The presented calculated dependences make it possible to determine what engine power of the base machine is required for the productivity of the trencher.

Formulas for calculating the productivity of the machine, taking into account the speed of movement of the base machine and the remote capacity of the equipment, allow you to determine the pace of the repair cycle using the advanced design of the digging machine.

The design of the cutter drum for removing soil from under the main pipeline with a diameter of 720 mm has been developed. The cutter drum is installed on trencher with dual trencher implement, and is mounted perpendicular to a copying tool. This design allows you to exclude a digging machine from the standard fleet of vehicles, which reduces the cost of its operation and relocation.

And it also allows you to dig up the pipeline in one pass, which in turn saves time that was previously spent on installing the digging machine. The proposed technical solution allows for capital repairs of pipelines with the replacement of the outer insulation coating without lifting the pipeline from the trench and maintaining its position.

The design of the equipment of a trencher for opening the pipeline and cleaning the annular space from the ground can significantly increase the productivity of the construction equipment involved in the repair work and reduce the time spent carrying out this kind of work.

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