Design and methodology for technological calculations of cable-winch traction plow ditchers

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Abstract. A current problem of drainage reclamion is the construction of a network of drainage canals or ditches. Existing technologies of an open drainage network ensure the use of single-bucket or rotary excavators, and with a ditch depth of up to 1 m it is required to use plow-type ditchers with two or three thrust tractors of T-170B type. It is possible to implement the required pulling forces for the operation of plow canal diggers using cable-winch draught. At the same time, a tractor with a winch-anchor passes, unwinding a tracking cable, along the route of the future channel, anchors and pulls the plow canal digger with the traction of the winch. On soils with a low bearing capacity, this principle of operation allows ensuring high flotation and efficiency factor, to realize the traction forces required for constructing a canal up to 1.7 m deep in one pass. Hereof it follows that the determination of the optimal design parameters of the units for forest reclamion work, as well as their mode work is relevant.

1. Introduction

The existing technologies for the construction of canals of an open drainage network provide for the use of single-bucket or rotary excavators, and with a ditch depth of up to 1 m it is required to use plow-type ditchers with two or three thrust tractors of T-170B type [1, 3, 7, 15, 16]. The results of comparing the listed machines with working bodies of various types show that the energy consumption for the development of 1 m³ of soil with single-bucket excavators, rotary excavators and plow canal diggers is 50, 10, and 1 unit of energy, respectively [6, 7].

Single-bucket reclamation excavators have good maneuverability, versatility, durable, reliable in operation, but low-performance and require a large number of control operations. Rotary excavators are more productive and provide high quality work. However, they have limited cross-country ability on soft soils, insufficient reliability, and poor transportability. Plow canal diggers are the simplest, most reliable and durable, provide a high quality of the canal being constructed, however, their use is limited by the need to apply large tractive efforts to pull the working body, which, at a digging depth of more than 0.6 m on soft soils, cannot be implemented with one tractor.

The implementation of the required pulling forces for the operation of plow canal diggers is possible with the use of cable-winch traction [2, 7, 11, 12, 13, 14]. At the same time, a tractor with a winch-anchor device passes, unwinding the traction rope, along the route of the future channel and, anchored, pulls the plow canal digger with the traction of the winch. On soils with a low bearing capacity, this
principle of operation allows ensuring high flotation and efficiency, to realize the traction forces required for constructing a canal up to 1 m deep in one pass.

Currently, the cable-winch traction is used on canal ditcher from Badger (Great Britain) and Lokomo (Finland) [12].

The aim of the work is to create a winch-anchor device for pulling the plow ditcher when performing land reclamation work, which makes it possible to implement traction forces of up to 12 tons with a cable length of up to 250 m on the pull of a DT - 75B tractor.

The research program included:

- study of the efforts of pulling the plow canal ditcher along the canal route;
- determination of power consumption for the implementation of the technological process;
- calculations of the area of the stop block of the anchoring device;
- justification of the design of the winch and the general layout of the unit.

The studies were carried out experimentally on a mock-up specimen of a trenching machine and theoretically, which made it possible to substantiate the parameters of the unit and its working body at the design stage.

The choice of the design of the ditcher and modes of its operation has been substantiated. Based on the results obtained, it is possible to determine the design and geometric parameters of the unit, which will increase labor productivity and reduce energy costs for performing the technological process. The performance of the ditcher remains the same in comparison with the pulling of the plow by the tractors T - 170B, the cost of work is reduced by 4 - 6 times. It is possible to use the tool for draining wetlands in agriculture and forestry, as well as for solving problems in civil defense and emergency situations when extinguishing peat fires.

2. Description of the research object

In our country and abroad, plow canal ditchers are used for constructing canals up to 1.5 m deep (dehumidifiers, temporary sprinklers, shallow discharge canals, etc.). The KM-1400M trailed plow canal ditcher is intended for operation in peat and peat-mineral soils of the drainage zone, the D-267A canal ditcher is used in irrigation zones [1].

Of the foreign plow canal ditchers, the trailed plow canal ditcher from Eversman Mfg. Co. (USA), Lokomo and A. Ahilstorom Osakeyto (Finland) are of great interest, as well as mounted plow canal ditchers from Caterpillar Traktor Co. (USA), Dampier Ltd (England), Fiskars (Finland), Dekker, Heen, Evenboer (Holland). Trailed plow canal ditchers H-5, D-5, D-6 and D-7 from Eversman Mfg. Co. (USA), are used for constructing new and for cleaning and restoring canals in operation.

At the same time, the winch is a more progressive traction device on soils with a low bearing capacity, which is associated with its stationary position during operation and only the rope moving with the ground. All the power of the winch engine, excluding the costs of its transmission, is spent on performing useful work.

The above provisions are confirmed by the reconstruction of the LKN-600 mounted ditcher into a cable winch, to the body of which, according to the theory of V.P. Goryachkin calculated the dimensions of the height of the fixed member of the hull, the length of the beam, taking into account the displacement of the application of force on the axle of the wheels, and other parameters [4, 12]. The first prototype of a cable-winch traction ditcher (KLK-1) was manufactured and tested in 1975. During the tests of the ditcher, measurements of the ditch cross-section, movement speed and tractive effort were made.

When testing KLK-1, the following disadvantages were noted:
1. The cable on the winch from the tractor LHT-55 was crushed on the lower turns and quickly fell into disrepair;
2. Frequent crossings reduce productivity due to insufficient cable length;
3. A single drum winch does not provide constant tractive effort along the length of the run.
3. Materials and methods

The disadvantage of the existing single-drum winches is the change in the tractive effort when winding the cable onto the drum due to the increase in the winding radius as the latter is filled, as well as the restrictions imposed by this in the length of the cable, leading to an increase in the number of plow pulling cycles. The existing drawback can be eliminated by using a winch with two traction sheaves. In these winches, traction is generated by friction between the cable and the sheave or traction drum.

The existing drawback can be eliminated by using a winch with cable-driven sheaves. In these winches, traction is generated by friction between the cable and the sheave. With real traction forces of 150 kN and the tension forces of the free end of the rope wound on the winding drum, within 1 - 2 kN, three grips of a pair of synchronously rotating cable sheaves are actually required. Drawings of the proposed construction of the drainage ditch unit are shown in figure 1.

![Figure 1. Drawings of the proposed construction of the drainage ditch unit.](image)

The unwinding of the cable of a double-drum winch should be carried out by disconnecting the cable-guiding sheaves and the winding drum from the shafts of their drives and forced unwinding of the cable by the tractor's tractive effort.

It is proposed to develop a winch for the DT-75B tractor for a plow ditcher of the KLK-1 type, which does not have the above disadvantages.

The winch should provide a plow ditcher with a cutting depth of up to 0.85 m and a slope of 1:1, a width of 0.3 m along the bottom for a distance of up to 200 - 250 m per cycle and ensure the safety of the traction cable. The unit must have a transport speed on a trailer of at least 40 km/h.

At the same time, the efficiency of using the tractor increases due to the elimination of skidding of the propellers and an increase in efficiency when pulling the plow.

The use of a project tool reduces the labor intensity and cost of work by reducing the cost of the tool, lighter weight, increasing the efficiency and productivity of using the tractor unit. The projected ditcher in the transport position with a winch-anchor device and an emphasis to the tractor type DT-75B is shown in figure 2.
Figure 2. KLK ditcher in transport position. 1 - lifting-lowering hydraulic cylinder of the wheel stop block, 2 - gearbox with a winch, 3 - frame, 4 - hydraulic cylinder for turning the stop, 5 - stop block, 6 - wheels, 7 - plow beam lock.

Cable-winch traction ditch for the DT-75B tractor is designed to perform the following types of work:

- drainage of waterlogged lands;
- fighting peat fires by localizing them with canals;
- pulling out stuck equipment.

The designed device, when performing the above work with the use of a winch-anchor device, replaces two or three T-10MB tractors.

The unit includes a DT-75B tractor, a winch-anchor device and a cable-winch traction ditcher (hereinafter referred to as KLK). In front of the tractor, a winding drum with a cable capacity of 250 m is fixed on the brackets; the winch-anchor device includes a two-drum winch. The winch is driven from the tractor PTO shaft through a gearbox. The winch and attachments are controlled from the driver’s seat by means of a hydraulic distributor.

The winding drum is driven by a separate MR-450 hydraulic motor installed inside the drum. At the rear of the unit, a hydraulically controlled stop block is mounted, designed to fix the unit when performing a technological process using a winch.

The unit works as follows. At the beginning of work, the tractor with the ditcher drives up to the place where the ditch is laid, disconnects the KLK from the transport position to the working position, turns off the winch drive and the tractor with the winch-anchor device moves away from the plow a distance of the cable length, then the stop block is lowered to the ground. The winch is turned on; the cable is reeled up through the cable sheaves onto the winding drum. At the same time, the stop block
goes deep into the ground to the full depth and keeps the unit from displacement; the winch pulls the plow ditcher, forming a drainage ditch.

After the completion of the ditch, the tractor driver (figure 2) lowers the stop wheels with the hydraulic cylinder 1, moves in reverse until the hooks in the rear part of the frame 3 are placed on the plow axle, with the hydraulic cylinder 4 turns the stop block until the plow wheel axle closes, interconnects the traction cable on the plow frame and, turning on the winch, folds it into the transport position, fixing it to the plow beam lock 7, after which it moves to the track of the next ditch.

The stop block area is determined by the pulling force of the winch.

4. Results and discussion

Calculation of the pulling force of the winch, the resistance force of the plow and the holding force of the stop block are presented.

Rated pulling force of the winch $F_{tr.,num} \text{, H}$ is determined by the formula

$$F_{tr.,num} = \frac{M_{en,num} \cdot i_{pow.red} \cdot i_{winch} \cdot \eta_{tr}}{R_b}, \quad (1)$$

where $M_{en,num}$ is the torque developed by the tractor engine, Nm;

$i_{pow.red}$ is gear ratio of the power take-off shaft (PTO) reducer;

$i_{winch}$ is gear ratio of the winch;

$\eta$ is the efficiency of the winch cable pulley drive transmission;

$R_b$ is the radius of the winch drum, m.

For the projected unit with $M_{en,num} = 442 \text{ Nm}$, $i_{pow.red} = 3.44$, $i_{winch} = 7.985$, $\eta = 0.95$ and $R_b = 0.21$ m, $F_{tr.,num}$ will be 109.8 kN.

To calculate the unit, you need to know the power balance of the unit. The total traction resistance of the canal ditcher will be 96 kN [6, 8, 13, 16]. This force corresponds to the pulling force of the selected winch. Traction reserve is 14%.

The power consumption $N_{mov}$ on the movement of the canal ditcher when performing the technological process at a speed of 0.5 m/s is determined by the formula

$$N_{mov} = \frac{F' \cdot V \cdot g}{\eta_x}, \quad (2)$$

where $F'$ is the total traction resistance of the tool, kN;

$\eta_x$ is the efficiency of the tractor and winch transmission mechanisms, which, according to reference data, is 0.85.

For the projected KLK $N_{mov}$ will be 56.4 kW, while the engine load factor for the unit with the DT-75B tractor will be 0.85.

The total traction resistance of the stop $F'$, kN for peat soils [4, 6] is determined by the formula

$$F' = 10^{-2} \cdot C_1 \cdot h^n, \quad (3)$$

where $C_1$ and $n$ according to [6] will make $C_1 = 39$, $n = 1.25$;

$h$ is depth of penetration of the stop block, cm;

$F'$ is 118 kN.

Additional traction resistance of the unit when slowing down the tracks of the base machine $F_\gamma$, kN, is determined by the expression

$$F_\gamma = G_m \cdot f_m kH \quad (4)$$

where $G_m$ is the mass of the unit, $G_m = 91 \text{ kN}$;

$f_m$ is resistance to movement of braked tracks, $f_m = 0.7$;

$F_\gamma = 63.7 \text{ kN}$. 


The total traction resistance of the unit will be 81.7 kN. The safety factor of the holding force of the stop is 1.89. The resistance to shear of the KLK stop is sufficient for the implementation of thrust.

Calculation of the pull-up force of the winding drum has been made.

The disadvantage of the existing single-drum winches is the change in the tractive effort when winding the cable on the drum due to the increase in the winding radius as the latter is filled, as well as the restrictions imposed by this on the length of the cable, leading to an increase in the number of plow pulling cycles.

The existing drawback can be eliminated by using a winch with cable-driven sheaves (figure 3), where the traction force develops due to friction between the cable and the traction drum. In this case, the free end of the cable must be tightened to prevent slipping of the rope in the traction drum streams.

\[ P = Q \frac{1}{e^{\mu \alpha}} \]

Figure 3. KLK double-drum ditcher winch. 1 – Winch body, 2 – axis of the cable-driving sheave, 3 – driven gear, 4 – handle for disabling the drive of cable-driven sheaves, 5 – cam clutch, 6 – cable-driving sheave.

The required tensile force \( P \) kN of the free end of the cable, wound on the winding drum, is determined by the expression [6].
pair of half-ribs of the cable-guiding pulley are determined by the expression [6]. The kinematic diagram of a double-drum winch with a winding drum is shown in figure 4.

\[
P_1 = S - S_1 = S \left(1 - \frac{1}{e^{2\pi \mu}}\right); P_2 = S - S_2 = S \left(1 - \frac{1}{e^{4\beta \mu}}\right)
\]

\[
P_n = S_{n-1} - S_n = S \left(1 - \frac{1}{e^{2(n-1)\pi \mu}} - \frac{1}{e^{2n\pi \mu}}\right)
\]

The total circumferential force is determined by the formula [6]

\[
P = \sum P_i = S \left(1 - \frac{1}{e^{2n\pi \mu}}\right) kN
\]

Since the speed of the cable wound on the winding drum changes during the transition from layer to layer, then its rotation speed must be variable, which is achieved by using a hydraulic drive. The pressure in the drive system is calculated from the condition of constant cable tension.

The unwinding of the cable of the double-drum winch is carried out forcibly due to the departure of the tractor, while the drive of the winding drum is turned off. The mechanism for shutting down the winding drum is made with a manual drive due to inconsistent use.

To calculate the holding force of the stop block, the formula of I. I. Mer was used [4], its applicability has been confirmed by experimental studies. However, it was designed to determine the pulling force of a cutting edge in peat soil. Further development of the methodology for calculating plow canal ditchers of cable-winch traction should go in the direction of theoretical and experimental study of the displacement of a peat deposit under the influence of forces applied in the horizontal direction, which will allow choosing the optimal geometric shape and dimensions of the stop block according to the criteria for their minimization.

5. Conclusion
The efficient operation of the plow ditcher can only be achieved with high tractive forces that cannot be achieved with a tractor alone. The implementation of the required pulling forces for the operation of plow ditchers is possible with the use of rope-winch traction. At the same time, a tractor with a winch-anchor device passes, unwinding the traction cable, along the route of the future canal and, anchored, drags the plow canal ditcher with the traction force of the winch. On soils with a low bearing capacity, this principle of operation allows ensuring high permeability and efficiency, to realize the tractive forces required for laying a channel up to 1.7 m deep in one pass. At the same time, the energy consumption of the technological process of the plow ditcher is an order of magnitude lower than that of other types of workers tools.
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