A device for gas dynamic loosening of the soil under the arable layer

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Abstract. The article introduces an innovative method for deep loosening of subsoil layers by harnessing the energy generated from detonation waves. This groundbreaking approach aims to improve soil structure and facilitate better water and nutrient penetration, ultimately enhancing agricultural productivity. The authors have meticulously designed and validated the parameters of a specialized device that operates non-contact, which allows for precise manipulation of the subsoil without direct physical interference. The research delves into the mechanics of soil destruction when subjected to the intense forces of a detonation wave, providing detailed models that illustrate the process. Additionally, the article outlines the rate of penetration achieved through this method and describes the formation of wells as a result of the controlled soil disruption. This technique not only promises to revolutionize traditional soil management practices but also offers potential applications in various fields, including environmental restoration and construction, contributing to more sustainable and efficient land use.

1 Introduction

It is known that to raise agricultural production to the world level, highly efficient machinery and technology are needed. Soil is the backbone of agricultural production. Therefore, it is necessary to constantly maintain and improve soil fertility. For this it is necessary to improve the land reclamation condition.

In the complex of agronomic measures included in the system of agriculture, one of the leading places belongs to soil cultivation, which contributes to an increase in effective fertility and ensures the production of high yields of agricultural crops. Improving the efficiency of irrigated land use is impossible without improving the fertility of the subsoil by deep tillage.

To loosen the subsoil with simultaneous plowing in SAIME, a plow with a soil deepener was developed. According to the research of M. Muradov [1], for the best depth and minimum traction resistance, the crumbling angle of the tiller's paw should be 22 °, and the opening angle 2y = 120 °.

In the cotton growing zone, with the current technology, as a result of tillage to the same depth, multiple passes through the field of tractors and other agricultural machinery, there was a strong compaction of subsurface horizons, reaching 1.4 ... 1.6 g / cm^3 in the main root

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zone, which is much exceeds the values optimal for cotton and other crops. These dense layers are practically impenetrable or difficult to penetrate for plant roots and water [10].

2 Materials and methods

The RN-80B subsoiler with one working body and two support wheels adjustable in height was designed for a loosening depth of up to 80 cm. It is aggregated with a T-100 MGS or T-130. Its working body is attached to a rectangular frame and consists of a vertical stand, in the front part of which there is a cutting replaceable knife with side cheeks and powerful chisels, fixed to the stand by means of a shoe. Chisel coverage 120 mm. Its disadvantages include high metal consumption, the impossibility of continuous loosening of the soil for cotton, high traction resistance and the impossibility of aggregation with the T-4A cotton-growing tractor [12].

In general, the problem with this phenomenon, i.e. the destruction of the compacted subsoil or arzyk layer of the soil has not yet been resolved. At present, there is no effective solution to this issue other than the use of detonation energy when decompaction of the arzyk layer of the soil. The central idea of research is to use as a "tool" the force of the detonation wave [13]. Detonation of conventional fuels (gasoline, gas) with air gives a power impulse with the following parameters:

- pressure in the shock wave 35 atm;
- flow rate of detonation products 800 m / s;
- movement of the detonation wave along the channel at a speed of the order of 1600 - 1800 m / s.

Such a gas-dynamic impulse, hitting any surface, acts on it as a sharp, short blow. The force of impact and its direction can be adjusted, for example, strictly perpendicular to the surface without lateral (shear) force components [11]. The "tool" is a gas-dynamic impulse, in contrast to the paw of the above-mentioned deep ripper.

During operation, the gas detonation tool exerts a force effect P (t) on the borehole bottom, which is of an impulsive nature. A single-acting impulsive load is understood as a short-term load of a constant direction, having no more than one maximum during its continuous action, it is represented by analytical expressions [9]: here t = 0 the beginning of the load; P = 0 its maximum; f (t) is a function characterizing the shape of the pulse, and the maximum will be at.

$$\left.\begin{array}{l} \mathrm{P(t)} = P_o\ f(t)\ at\ 0 \le t \le \tau \\ P(t) = 0 \quad at\ t \succ \tau \end{array}\right\} \tag{1}$$

The change in the stress state of the soil mass under the action of a gradually increasing load on it is a process characterized by a certain pattern and type of deformation. When drilling holes with the installation of a gas-dynamic soil cultivator (GDRP), compaction, shearing and bulging occurs in the soil. The phase of change in the stress state of the soil can be graphically represented by the graphical curve S = f (p), built in the coordinate system S (precipitation) and P (load) (Fig. 1).

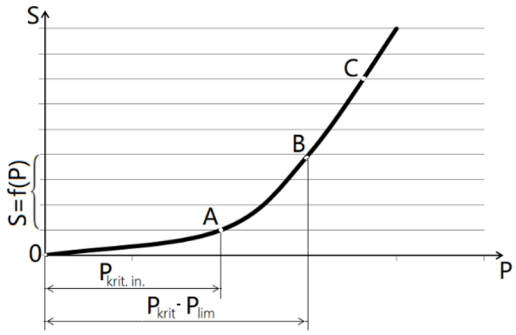

Fig. 1. The phase of change in the stress state of the soil: OA-phase of compaction; AB phase shift; Sun-loss of stability.

The first phase will correspond to a straight section OA with the coordinates of the extreme point SA and Pcr. With an increase in the load P> Pcr., The characteristic dependence S = f (P) becomes nonlinear. The intensity of the increase in precipitation is ahead of the intensity of the increase in the load. The curvilinear section AB characterizes the second phase-phase of the development of the strike-slip. With a further increase in the load P, the slope of the curve increases, characterizing the "out-of-limit" state of the soil, accompanied, depending on the deepening of the detonation tube, either by the soil bulging to the surface, or by progressive fluidity inside the soil mass. In both cases, the thick soil loses its stability.

In the second phase, immediately after the end of the compaction phase, under the detonation wave, compacted core 2 begins to form (Fig. 2). This core, penetrating into the soil with an increase in the load P> Pcr, pushes its particles to the sides, which causes the growth of cracks in the soil [15].

3 Results and discussion

When the load P shear zones appear on both sides of the core, in which continuous sliding surfaces are formed. The boundary of these zones and their sizes, under equal conditions, depend on the depth of penetration of the detonation tube. With a relative maximum depth h / dp <0.5, soil deformation is characterized by soil uplift from under the detonation tube. When h / dp <0.5, plastic deformation zones cover a certain area on all sides of the core [16].

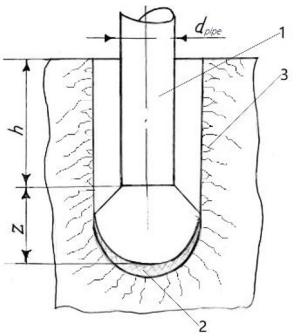

Fig. 2. Dense core for detonation waves: 1-detonation tube; 2- compacted core; 3-cracks.

The above indicates the importance of studying the nature of the formulas for determining the critical loads P and Pkr, since they make it possible to determine the minimum load for drilling holes with the installation of gas detonation loosening of the soil.

V.V.Puzirevsky was the first to solve the problem of determining Pkr. with respect to soil mechanics [2]. The soil is considered as its own body, and the pressure from its own weight of the soil is subject to the hydrostatic law. The solution uses one of the forms of limiting equilibrium (Fig. 3). At point M, the main stresses σ1 and σ2 arise. However, since h, additional sealing pressure appears, i.e.

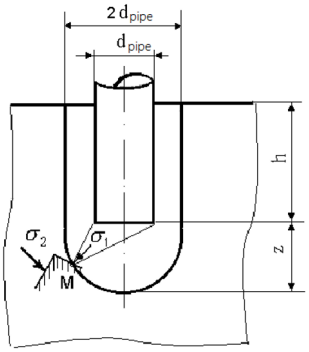

Fig. 3. Design scheme for determining Pkr.

P-yh in place P At the point located in the limiting state, the angle between the two slip lines is called the angle of visibility, and it is determined by the ratio. Based on this ratio and taking into account the stresses from the own weight of the soil, the main stresses at the point M, which lies at a depth Z from the open end of the detonation tube. The relationship between the main stresses is determined by the well-known formula

$$\sigma_1 - \sigma_2 = (\sigma_1 + \sigma_2)\,\mathrm{Sin}\varphi + 2C\,\mathrm{Cos}\varphi \tag{2}$$

But

$$\left.\begin{aligned}\sigma_1 &= \frac{P-\gamma h}{\pi}\left(\frac{\pi}{2}-\varphi+\cos\varphi\right)+\gamma z+\gamma h\\ \sigma_2 &= \frac{P-\gamma h}{\pi}\left(\frac{\pi}{2}-\varphi+\cos\varphi\right)+\gamma z+\gamma h\end{aligned}\right\} \tag{3}$$

Substituting expressions (2) into equation (3) solving it with respect to P = Pkr we obtain

$$P_{кр} = \frac{\pi}{ctd\varphi-\frac{\pi}{2}+\varphi}\left(\gamma z+\gamma h+Cctd\varphi\right) \tag{4}$$

Formula (4) represents the limiting or critical pressure on the ground from the detonation wave, in which the soil loses its limiting state and the soil shifts.

To carry out experimental studies to study the possibility of drilling holes using the energy of detonation waves in order to improve the reclamation state of arzyk-shokhovy soils, the following layout of the experimental setup was proposed, discussed and adopted, which consists of three main parts: a tractor, a mixer for the formation of a detonation-like fuel-air mixture and working body.

The selected tractor T-28X4M, which, in combination with cultivators, is equipped with a gas-dynamic soil cultivator (Fig. 4) [13].

Mixer of fuel-air mixture: The gasoline-air mixture preparation system (hereinafter the mixture preparation system, ATP) is designed to form and supply a mixture of gasoline with air in a certain proportion to the working bodies. ATP includes the following main elements:

- air compressor ("VR-8 / 2.2");
- main gas tank with fuel level indicator;
- a consumable gas tank with a bypass valve, a strainer and a drain valve;
- gasoline supply line with locking elements;
- air line for pressurizing gasoline in a consumable gas tank;
- confuser with a throttle washer;
- nozzle unit with a jet, a cone-splitter and a screw for adjusting the mixture composition;
- oil separator ("Cyclone" type).

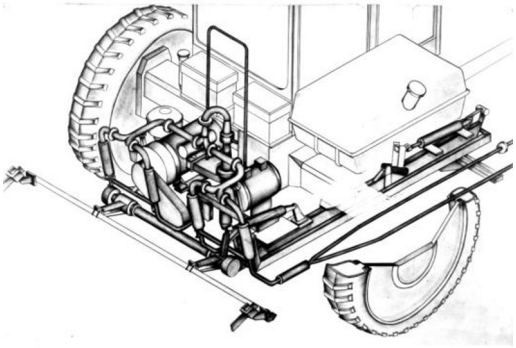

Fig. 4. Gas-dynamic soil cultivator.

The air-fuel mixture preparation system works as follows (Fig. 5): air from compressor 1, driven from the rear PTO shaft of the tractor through a double articulated clutch, telescopic and intermediate shafts, as well as a chain drive, enters confuser 2 , where it accelerates in its narrow section.

Part of the air is taken by tube 14 to pressurize the gasoline in the supply gas tank 8. In this case, excess pressure (0.4 atm.) Is formed due to the hydraulic resistance on the throttle washer 15 installed behind (downstream) the point where the pressurizing air is taken.

On command from BZK 18, solenoid valve 11 opens (in this case, the mechanical gas valve 12 is open) and gasoline enters the injector unit, where, flowing out of the nozzle 3, it is cut by a high-speed air flow in a narrow section of the confuser 2.

Below (downstream) nozzle 3 there is a splitter cone 4, intended for a more uniform distribution of the spray of gasoline spray over the pipe cross section.

The air leaving the compressor has a temperature of about 80-90 ° C and therefore the gasoline-air mixture heats up and enters the combustion chambers 20 in a vapor state.

Simultaneously with the signal to open the solenoid valve 11 from the control and monitoring system 18, high-voltage pulses are sent to the electric spark plugs 19, screwed into the side walls of the combustion chambers 20.

When the compressor is off (when the tractor is turning at the end of the field), there is no excess pressure in the fuel tank and gasoline from the main gas tank fills its volume by gravity through the bypass check valve 7.

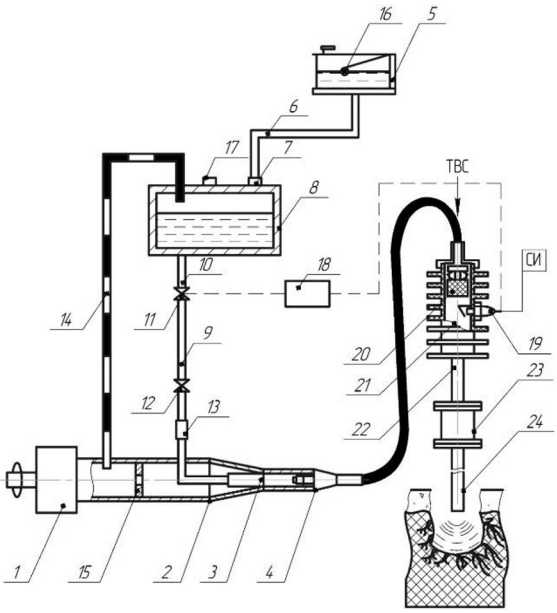

Fig. 5. Diagram of the fuel-air mixture preparation system: 1 compressor; 2-confuser; 3-jet; 4-cone diffuser; 5-main gas tank; 6-copper tube; 7-check valve; 8-consumable gas tank; 9,10,14-tubes; 11,12 valves; 13-drive; 15-throttle washer; 16-float; 17-mechanical gas crane; 18-control and monitoring system; 19 spark plugs; 20 valve; 21-camera sgrony; 22-pipe; 23-pipeizer; 24-detonation tube.

Working body of the experimental installation: The detonation tube (DT) is the main working element of the experimental setup. Taking into account the productivity of the "Mixer", eight diesel fuel are used in the installation.

The quality work of diesel fuel can be described as follows. The working cycle of diesel fuel is characterized by 4 independent stages:

- filling diesel fuel with a fuel-air mixture (FA);
- initiation of detonation combustion;
- combustion of fuel assemblies in diesel fuel;
- the outflow of combustion products (PS).

Before the first initiation of the diesel fuel, the fuel assembly is filled. The pressure in the diesel fuel is equal to atmospheric. Further, near the closed end, detonation combustion is initiated [17]. At the closed end of the diesel fuel, the pressure P is instantly established [18]. The detonation wave propagates along the diesel fuel to its open end, where the sound outflow of the PS into the atmosphere begins, and a vacuum wave propagates to the closed end of the diesel fuel [19]. Since the PS in the diesel fuel is accelerated to high speeds, a "piston effect" takes place, and the pressure in the diesel fuel drops below atmospheric. The pressure difference in the diesel fuel and the "Mixer" contributes to the suction of a fresh portion of fuel assemblies [20]. After filling the pipe with the mixture, the cycle is repeated.

In order for the diesel fuel to work in this mode, a number of conditions must be met:

a) it is necessary to prepare a detonation-capable fuel assembly capable of burning mixed with air in strict accordance with the concentration limits;

b) fill the pipe with the mixture in a short time;

c) initiate detonation combustion;

d) exclude spontaneous ignition of a fresh portion of the mixture.

The valve design is shown schematically in Fig. 6. The valve cascade (I) is a round plate with holes for the passage of fuel assemblies. It is designed to ensure the maximum flow area.

The flame arrester (4) is a body filled with mesh discs. The number of disks is selected on the basis of the condition of stable operation of the diesel fuel at any operating frequency without failure to flame.

Ignition chamber 3 (Fig. 5) will be made in the form of a tube with an inner diameter of 50 mm with external ribbing. At the inlet of the chamber there are: a device for supplying fuel assemblies and a flame-blocking valve, and with an outlet flange it is connected with a pipe of a smaller diameter with a tubularizer. In the ignition chamber, a fresh charge of the fuel assembly is ignited by a high-voltage electric pulse on the electrode of the spark plug (5) from the "Initiation System". To protect the spark located in the high-speed gas flow, the spark plug is placed in a cylindrical screen - futur (4) with an open end cut at an angle of 45 °. For stable operation of the diesel fuel in the frequency range from I to 50 Hz, the footboard has 4 holes with a diameter of 2 mm for blowing it out of PS residues and guaranteed filling the near-spark space with a fresh mixture.

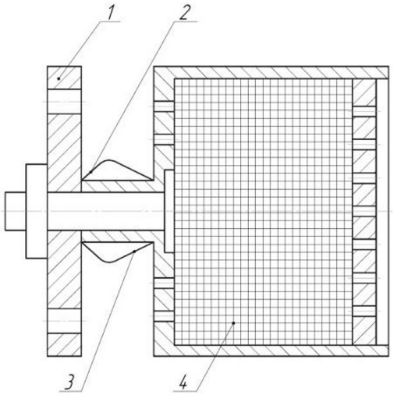

Fig. 6. Diagram of the check valve assembly: 1 - valve lattice; 2 - petal valve; 3 - limiter; 4 - flame arrester.

The ignition chamber is introduced into the diesel fuel structure to increase the speed of the flame front at the inlet to the turbulator (6). The necessary effect is created by an increase in the cross-sectional area of the ignition chamber in comparison with the pipe at the inlet to the turbulator. The turbulator (6) will be made in the form of a pipe section with an inner diameter of 50 mm with flanges at the ends. It plays the role of a flame accelerator, since there is a strong influence on the length of the pre-detonation section.

The pipe (7) is the main working volume of the diesel fuel. Here the flame front accelerates to detonation combustion. The energy output of one cycle depends on the value of this volume. The pipe is made as a separate unit and is a pipe with an inner diameter of 25 mm with flanges at the ends.

An alarm sensor (8) is used for continuous remote monitoring of shock wave impulses. Its readings are recorded on the operator's console.

The nozzles (9) are replaceable DF units and are used to direct shock waves to the treatment object. They are made in the form of a bent pipe with an inner diameter of 25 mm and with one flange at the end.

4 Discussion

The aggregates and tools used today, which deeply loosen the cultivated areas, are intended only for loosening the arable part of the land. Therefore, we have proposed a new method of deep loosening of arable soil, which is a device based on the use of detonation wave energy, which has not previously been used where required.

5 Conclusion

Deep loosening of the soil shows that it is an important agricultural technique for eliminating the compaction of subsoil layers. After deep loosening of the subsoil, the water-air, nutrient and thermal conditions of the soil improve, which makes it possible to increase the productivity of agricultural crops.

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