Development of a Weeding Robot with Tubular Linear Electric Motors

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Abstract. The use of chemical methods of weed control is an effective means of weed control. However, the use of large amounts of herbicides leads to environmental pollution, contaminates food, and adversely affects the health of people working with chemical herbicides. The safest method is to mechanically remove weeds by pulling the rooted weeds out of the soil or cutting and driving the weeds under the soil. Robots use pneumatic, hydraulic, or electrical systems to control weed cutters. Electrical systems are more efficient than other systems. It is proposed to use a tubular linear electric motor to drive the weed remover. An experimental sample of a tubular linear electric motor has been manufactured. His experimental studies showed that at a current of 8 A, the mechanical force from the movement of the movable rod is 500 N, and this value is sufficient for an actuator for weed control. Based on the results of experimental studies, a scheme of a weeding robot with two tubular linear electric motors has been developed to drive the weed control mechanism in the horizontal and vertical planes.

1. Introduction
The advancement of robotics is leading to new ways of using robots in agricultural production. One of the ways robots are used in agriculture is weed control. Every year, weed infestation causes huge losses in agricultural production around the world. A large amount of labor and herbicides are used annually to control weeds. The use of chemical methods of weed control is an effective means of weed control. However, the use of a large amount of herbicides leads to environmental pollution, contaminates food, and adversely affects the health of people working with chemical herbicides [1–2].

There are also herbicide-resistant weed varieties and there is a growing demand among the population for chemical-free products. Also, weed control is one of the most tedious operations in vegetable growing, it requires a lot of labor, time, and is accompanied by mistakes and human fatigue when performing routine repetitive actions [3–5]. Therefore, the safest method is the mechanical method of removing weeds by pulling the weeds out of the soil by the roots or cutting and driving the weeds under the soil. To perform this work, robots are equipped with a control and navigation system, a computer vision and weed recognition system, as well as devices for removing weeds - saw teeth, flat blades, nylon brushes, flexible teeth [6–8].
Some robots use pneumatic, hydraulic, or electrical systems to control weed cutters. Many authors in their research works propose to use electric motors, since electric motors have a number of advantages over others: a) electrical systems have a faster response compared to hydraulic systems, b) electrical systems can be controlled more accurately than hydraulic systems, c) electricity consumption can be easily controlled using the electrical system to understand the effect of ground depth, travel speed and other factors on the required power, d) electrical systems do not leak and do not cause soil pollution [9–11].

The robot and the installed equipment must have a power source, most often electric batteries are used. Also, the robot must have a drive to move the blade to remove weeds. Typically, such a weeding drive consists of a belt or gear drive system driven by an integral servo motor and a rotating weeding gear driven by a brushless DC motor. The brushless DC motor is also used to move the robot through the plants. The use of a belt or gear drive leads to an increase in electricity consumption, and accordingly the number and weight of batteries increases. The increased weight of the batteries will increase the overall weight of the robot weaver, which will require more powerful and heavier brushless DC motors and make the robot weaver stationary and sedentary. Such a robot will not have high mobility and accuracy when removing weeds, and in addition to destroying weeds, it can damage cultivated plants [12–14].

Therefore, for successful weed control both in the row spacing and in the row spacing, it is necessary to have a drive that is easy to operate, has high accuracy, low inertia and does not contain rotating parts such as DC motor. Such a drive is a linear electric motor [15–17].

The linear motor does not contain rotating parts, but consists of a moving part and a stationary part. The stationary part of a linear motor that receives electricity from the mains is called the stator or primary element, and the part of the motor that receives energy from the stator is called the secondary element or armature. The secondary element moves along a straight path and has a high movement accuracy.

2. Materials and methods
The purpose of the research is to use a linear electric motor to drive an executive mechanism of a weeding robot, as well as to develop a scheme for a weeding robot with a manipulator based on a linear electric motor [18–19].

When conducting scientific research, methods of planning a multidimensional experiment, statistical processing of experimental data and determining the adequacy of data were used. In experimental studies, certified measuring instruments were used: an ammeter, a voltmeter, a constant voltage regulator, a device for measuring mechanical force – a dynamometer, a tripod for taking the static characteristics of a linear electric motor [20–21].

To measure the static characteristics, a tubular linear electric motor was manufactured, consisting of a fixed part – a stator and a movable armature rod. A tubular linear motor is a type of linear electric motor consisting of a series of solenoids wrapped around a cylinder enclosing a movable rod that contains a series of strong cylindrical permanent magnets aligned in alternating and opposite directions. A constant electric current is supplied to the solenoids via wires.

![Figure 1. A series of stator solenoids for a tubular linear electric motor.](image-url)
Figure 2. General view of a tubular linear electric motor: 1 – wires for electric direct current, 2 – a cylinder with solenoids, 3 – permanent magnets of the opposite direction, 4 – a movable rod.

3. Results and discussion
During the experimental studies, a constant electric current was applied to a number of solenoids, the movable rod was moved, and the force from the movements was measured by a dynamometer. The results of the studies are presented in table 1.

| Electric current, I, A | 8    | 10   | 12.5 | 15   | 17.5 |
|-----------------------|------|------|------|------|------|
| Mechanical force from displacement, F, N | 500  | 950  | 1400 | 1850 | 2150 |

| Electric current, I, A | 20   | 23   | 26   | 29   | 32   |
|-----------------------|------|------|------|------|------|
| Mechanical force from displacement, F, N | 2400 | 2650 | 2800 | 2950 | 3100 |

The results of experimental studies allowed us to establish that at a current strength of 8 A, the mechanical force from the movement of the movable rod is 500 N, and this value is sufficient for the executive mechanism for the destruction of weeds. An increase in the electric current of more than 8 A is also sufficient to kill weeds, but this will lead to an increased charge consumption and battery life, reduce energy savings, and therefore is redundant.

Based on the results of experimental studies, a scheme of a weed weeding robot with a tubular linear electric motor for driving the weed killing mechanism has been developed.

The unmanned weeding robot consists of a frame 1, on which a control and navigation system 2, storage batteries 3, a plant detection and recognition system 4, four wheels 5 for movement, each of which contains racks 6 with a rotary mechanism and is driven by a separate DC motor 7 through a rotating shaft 8, as well as two tubular linear electric motors.

The first tubular linear electric motor consists of a fixed set armature 9, made of magnetic inserts 10 and non-magnetic rings 11, and a movable stator 12 with a solenoid inside. The fixed set anchor 9 is fixed to the frame 1. The movable stator 12 moves along the fixed set anchor 9 by the interaction of the magnetic field created in the solenoid located in the stator 12, magnetic inserts 10 and non-magnetic rings 11.

The second tubular linear electric motor consists of a fixed stator 13 and a movable set armature 14, also consisting of magnetic inserts 15 and non-magnetic rings 16. The stationary stator 13 is connected perpendicular to the movable stator 12.

A DC motor 17 is attached to the lower end of the movable set anchor 14, which rotates the cutting tool 18 for mechanical weed removal 19.
The unmanned weeding robot works as follows.

According to the commands of the control and navigation system 2, with the help of DC motors 7, which drive the wheels 5 through the rotating shaft 8, the unmanned weeding robot moves in rows with plants. To increase maneuverability in rows with plants, each wheel 5 is equipped with a rack 6 with a rotary mechanism that allows you to turn the wheel 5 to any desired angle of rotation. With the help of the plant detection and recognition system 4, the coordinates of the placement of the weed plant 19 are determined, and the weeding robot stops over it.

By means of two tubular linear electric motors, the cutting tool 18 is moved for mechanical removal of weeds in a vertical and horizontal plane. The first tubular linear electric motor moves in a horizontal plane. The movable stator 12 moves along the fixed set anchor 9, thereby positioning the cutting tool 18 above the weed. To destroy the weed, the cutting tool 18 must be raised and lowered. Lifting and lowering of the cutting tool 18 is carried out by means of a second tubular linear electric motor. The stationary stator 13 of the second tubular linear motor is connected perpendicular to the movable stator 12 of the first tubular linear motor. Inside the stationary stator 13, the movable set anchor 14 moves in...
the vertical plane. The movable set anchor 14 is lowered to the level of the weed, then the DC motor 17 rotates the cutting tool 18 for mechanical removal of weeds 19.

Thus, an unmanned weeding robot, in automatic mode, with a high degree of accuracy, destroys weeds in rows and row spacing, without touching cultivated plants.

4. Conclusion
1. The use of tubular linear electric motors improves the accuracy of weed control, reduces the risk of injury to crops and reduces energy consumption in the field.
2. Mechanical methods of weed control are accurate and environmentally friendly.
3. The use of tubular linear electric motors improves the accuracy of weed control, reduces the risk of injury to crops and reduces energy consumption in the field.
4. At a current strength of 8 A, the mechanical force from the movement of the movable rod is 500 N, and this value is sufficient for the executive mechanism for the destruction of weeds.

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