Application of flywheel energy accumulators in agricultural robots

N N Barbashov and A A Barkova*

Bauman Moscow State Technical University, Theory of machines and Mechanisms Department, 2nd Baumanskaya st., 5/1, Moscow, 105005, Russian Federation

*E-mail: anastasiia_barkova@mail.ru

Abstract. For the development of the agricultural industry, the current task is to design mobile robots that can independently perform a wide range of tasks. In this area, it is necessary to achieve both a reduction in the mass of the robot to reduce its impact on the top layer of soil, and an increase in its operating time without recharging from batteries. A promising method for improving the efficiency of agricultural machinery is the use of braking energy recovery, its accumulation and use during further acceleration. In this case, efficiency increases without reducing the dynamic qualities and performance of the equipment. The use of a flywheel energy accumulator allows you to use energy recovery in agricultural machinery, without resorting to difficult-to-maintain and relatively low-life batteries.

1. Introduction

Currently, the agricultural industry is tasked with improving production and quality, as well as improving technological processes. In particular, we consider the introduction of robotics, which makes it possible to simplify many actions, perform work in dangerous environments for human life, and eliminate uncertainty in the field of agricultural production management associated with the unpredictability of human behavior. Devices for automatic soil cultivation, crop processing, and harvesting are being actively designed and implemented.

Various organizations demonstrate robot projects that allow you to efficiently harvest almost any crop, from small berries like strawberries and currants to apples and plums. Most robots have a navigation system that allows you to move along a given path using GPS and perform the required actions. For example, Bosch in 2015 showed the work of BoniRob, which allows you to eliminate weeds offline. Using a high-resolution camera, the robot finds the shoots of weed plants and tramples them into the ground a few millimeters using a special manipulator.

Figure 1. Scheme of the BoniRob robot device.
The Japanese Kubota tractor runs on electricity, powered by lithium-ion batteries and solar panels. It can move independently along the route, guided by GPS systems, on-Board sensors and artificial intelligence responsible for navigation. The robot's computer determines the weather condition and estimates the growth of crops, analyzes various factors and decides when it is time to leave and start sowing, cultivating the soil or harvesting.

![Kubota Agricultural tractor](image1.jpg)

**Figure 2.** Kubota Agricultural tractor.

Similar developments are being carried out in the Russian Federation. The Agrobot tractor allows you to fully automate field farming and solve a large number of agricultural tasks related to land cultivation, mowing grass, planting crops, watering plants, processing and weeding, as well as transportation of goods and crops. The robot has an unmanned control system. Various work scenarios are provided, from the possibility of tracking and training on the route in the following mode to moving along a given trajectory from the starting point to the end point. While moving, the robot can avoid or overcome obstacles, move along an inclined surface with different terrain, and assess the possibility of collision with moving objects. Any attachments can be installed on the tractor, depending on the goals set for it.

![Agrobot Tractor](image2.jpg)

**Figure 3.** Agrobot Tractor.

In the designs of modern agricultural robots, electric batteries are often used as a source of energy necessary for movement or operation of equipment. It is known that their disposal is harmful to the environment, which is an environmental problem [1]. Their energy usually lasts from 1 to 4 hours of operation, depending on the battery capacity, the size of the robot and the actions it performs. In many cases, this time is not enough, and the robot has to return regularly to recharge the battery. When harvesting, this usually slightly reduces the productivity of the robot, since it still has to return to empty the container with the collected products. But for other operations, such as weeding, the duration of the robot's Autonomous operation is an important parameter.

The main reasons for the increase in energy consumption are their operation in unsteady modes with frequent alternation of acceleration and deceleration [2]. A characteristic feature of mobile agricultural
robots is that the movement of working links mainly occurs in the acceleration and deceleration mode, and therefore the total amount of forces in the system is dominated by inertial loads. The main power of the engine is spent on acceleration of moving links, and the increase in speed due to increased engine power is limited by the fact that the additional moment of the more powerful engine from the catalog is mainly spent on overcoming the additional inertial load of acceleration of the more massive rotor of the selected engine. In terms of power consumption parameters, such devices are ineffective.

The actions performed require expanding the technological capabilities of agricultural robots, providing multi-position, adjustable values of movement of working links and their speeds with different sequence of movement directions.

One of the methods for improving the energy efficiency of robots is the development of structures with energy recovery, in which the kinetic energy of moving links is accumulated in the battery during the braking stage, and then used for acceleration during the next movement. In such designs, inertial forces do not affect the engine's setting power, whose function is only to compensate for friction losses.

2. Historical information
One of the first scientists to use flywheel battery on the practice N. V. Gulia. The inventor set himself the goal of inventing a technology that allows you to efficiently store and release energy, while having a high efficiency. His research shows that the use of a flywheel drive with mechanical power take-off instead of any other type of drive in a hybrid power unit will significantly reduce energy losses. The kinetic energy of the flywheel is also converted into the kinetic energy of a high-efficiency transport device.

The flywheel drive with mechanical power selection designed by N. V. Gulia exceeds all other types of drives in terms of specific energy consumption, efficiency and specific power. In 1972-73 N. V. Gulia successfully tested city buses with flywheel hybrid units. Fuel economy, depending on the speed and number of stops on the route, reached 50%. But his invention was not further developed due to the fact that switching modes of the recovery device could only be carried out manually, which significantly complicated its operation.

Usually flywheels that are used in the transport and lifting industry have a significant mass and size. There are cases when the weight of the flywheel reached 250 kg, which is completely unacceptable for agricultural robots. But modern microprocessor technology easily implements automated control of energy storage mechanisms, without requiring manual control and switching modes, and composite materials and alloys allow you to create a flywheel of small dimensions that can accumulate the required amount of energy.

In some models of agricultural robots, energy recovery is used using an electric battery, but even modern batteries often need to accumulate and release energy quickly enough to lose capacity. In such situations, the flywheel energy accumulator is most effective for regenerating braking energy. By the value of the specific energy reserve per unit of weight, the flywheel battery effectively competes with the electric one, differing from it by a higher service life.

3. Calculation
Depending on the task performed by the robot, the flywheel battery can perform different functions. If necessary, it can supply power to various equipment, such as a manipulator for harvesting or weeding. When the robot moves along, the energy generated by the electric motor will exceed the energy required for movement. Part of the free energy of the batteries can be used to spin the flywheel while the robot is moving. When the robot moves on loose soil or climbs a hill sharply, the energy stored by the flywheel can be used to overcome a difficult section. The simultaneous use of flywheel energy and electrochemical batteries will significantly improve the dynamic qualities of the agricultural robot.

When braking or driving downhill, energy recovery will allow you to spin the flywheel when it is not fully charged. If the flywheel is spun up to the maximum number of revolutions, it is possible to recharge the batteries with the energy of the flywheel. In addition, the use of a flywheel energy accumulator will smooth out peak current loads during start-up modes.
The amount of stored energy is proportional to the inertia of the rotating body of the flywheel $J$ and the square of the angular velocity of rotation $\omega$. It is determined according to the formula:

$$E_f = \frac{J_f \cdot \omega_f^2}{2}$$

The formula shows that the kinetic energy stored in the flywheel has a linear dependence on the moment of inertia of the rotating mass of the flywheel body and a quadratic dependence on the speed of rotation. Accordingly, as the rotation speed increases, the amount of stored energy will grow exponentially.

As a rule, a lot of revolutions of the flywheel battery is required to obtain the necessary energy, especially given the high requirements for overall dimensions in robotics. In some cases, the number of revolutions of the flywheel reaches 50-80 thousand revolutions per minute. At this speed, the flywheel must be placed in a vacuum chamber to reduce aerodynamic losses. It is necessary to install the shaft in magnetic bearings [3], since roller bearings are not suitable for use at high speeds, which lead to cracking and destruction [4]. The mathematical model of the bearing takes into account the centrifugal and Coriolis forces [5,6,7].

To spin the flywheel to such speeds, an additional reversible electric machine of low power is installed on the robot. Many companies implement an energy storage module in a single unit to simplify the design solution.

When calculating the cyclical efficiency during the movement of the agricultural robot, we compared the “acceleration – deceleration” cycles, which are identical in dynamism with and without energy recovery when the recovery coefficient is varied:

$$k = \frac{M_{dec}}{M_{ac}}$$

This coefficient is the ratio of the power of the recuperating devices and the main engine.

Analysis of the calculations allows us to determine the following:

- the efficiency of the cycle without recovery increases with increasing braking time due to the use of accumulated kinetic energy to overcome the useful resistance and becomes maximum when the car runs out with the engine turned off.
- during sudden braking with the maximum braking moment, the cycle efficiency without energy recovery decreases and becomes low and constant.
- while maintaining the total power of the main and booster engines, the use of energy recovery increases efficiency without compromising dynamic qualities and without reducing productivity.

![Figure 4. Dependence of the cycle efficiency on the recovery coefficient.](image)
4. Conclusion
Flywheel energy accumulators have a lot of positive qualities, such as simplicity of design, low energy loss, low cost, size and weight.

The use of a flywheel energy accumulator can reduce energy consumption and increase the productivity of the agricultural robot.

The use of a flywheel in robotics will increase the durability of batteries, including by reducing peak loads during start-up modes.

The possibility of manufacturing a flywheel made of titanium alloy or composite materials allows you to get a battery of small dimensions and weight, suitable for use in robotics [8,9].

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