DOI: 10.22620/agrisci.2021.30.010

DETERMINING THE ENERGY EFFICIENCY OF AN AGROROBOT

Ivan Mitkov, Veselin Harizanov, Georgi Komitov*

Agricultural University – Plovdiv

***E-mail: gkomitov@abv.bg**

Abstract

The problem of feeding the population and the lack of trained staff for growing crops is increasing all over the world. This inevitably leads to a change in technology for growing crops. These new technologies rely on autonomous robotic systems for the continuous cultivation of crops without human personnel. Robots are small, smart, interconnected, lightweight machines that aim to release the person from the basic everyday pursuits. Globally, there is a trend in agriculture to automate the hard manual labor with continued increases in yields to feed the population. This article discusses the problems of determining the main energy aspects of agricultural robots. Guidelines are given for determining the energy saving of the robot, depending on the time for its long autonomous operation, the terrain to be cultivated and a number of other factors. Exemplary values of the energy required to drive the agricultural robot and the time for energy recovery through renewable energy sources have been determined.

Key words: energy, RES, agrorobots, autonomous work.

INTRODUCTION

The growing population on earth leads to an increased demand and consumption of food. To maintain itself, the human body needs both animal and plant products. The increasing consumption of food requires an increase in the amount of agricultural production. This will inevitably lead to a change in the crop cultivation technologies.

The agricultural sector is labor-intensive and depends mainly on manpower. However, in countries where labor is scarce, the cost of hiring agricultural workers is too high, and hence the cost of agricultural production is high. There are tendencies towards great automation of agriculture. The necessary automation is not only during the whole technological process of growing plants, but also during the storage and transportation of agricultural products (Celen, 2015).

Many engineers have worked on driverless tractor development in the past, but they have not been successful so far because the agrorobots do not have the ability to perceive the complexity of the real world. Most of them adopted a production style of agriculture, where everything was known in advance and the machines could work entirely in predetermined ways - similar to a production line. The approach now is to develop more intelligent machines that are intelligent enough to operate in an unmodified or semi-natural environment. These machines must not be intelligent in the way we see people as intelligent, but they must behave sensibly in a recognized context. Thus, they must have enough intelligence built into them to behave sensibly for long periods of time, unattended, in a semi-natural environment while performing a useful task (Blackmore, 2005).

For many years, robotic systems have been widely used for industrial production and in warehouses where a controlled environment can be guaranteed. In the agricultural sector, driverless vehicle research is a vision initiated in the early 1960s with basic research on projects for automatic steering systems and autonomous tractors (Pedersen, 2008; Wilson, 2000).

Research on agricultural technology focuses mainly on increasing the efficiency of crop production. Production efficiency can be optimized by improving the behavior of the machines as well as by creating better growing conditions. Small and intelligent autonomous machines have the potential to contribute significantly by using more multifactor real-time sensors and incorporating mathematical modeling of technical and biological parameter interactions (Griepentorg, 2012).

In many cases, the use of a certain technology for growing crops is associated with a certain energy consumption (Sevov, 2012). In order to determine the efficiency of a given technology, it is necessary to compare the energy costs when using different technological routes. The article is based on the determination of the energy needed to drive an agricultural robot and perform a certain type of activity. Examples are given for determining drive motors and motors for performing a certain type of work. It is assumed that green energy from RES is used to charge the batteries of the robot.

MATERIALS AND METHODS

The energy required to drive the robot is expressed in determining the required power to drive and operate the agricultural robot. It must cover all energy consumers for its movement, for additional equipment, as well as a certain stock of 10-15%. The power required for the work of the agricultural robot P_e can be expressed by the dependence (1) (Dimitrov, 1997; Dimitrov, 1975):

$$P_e = r.\left(\frac{P_C}{\eta} + \frac{P_O}{\eta_O}\right), (1)$$

where PC is the resistance of its self-movement, W;

PO - power for equipment, W;

r - power reserve factor;

η - efficiency of power transmission from the engine to the drive axle;

ηO - efficiency of power transmission from the engine of the equipment to the executive unit.

To determine the resistance power, the dependence (2) is used (Dimitrov, 1975):

$$P_C = (??F_C + F_T).v, (2)$$

where v is the speed of the moving robot, m / s;

ΣFC - sum of the resistance forces during robot movement, N;

FT - traction resistance, N.

The sum of the resistance forces when the robot moves is expressed by the dependence (3) (Dimitrov, 1975):

$$??F_C = F_f + F_W, (3)$$

where F_f is the force of the resistance to movement, N;

F_W - force of the air resistance, N.

The robot has a low speed of self-movement of the order of 0.83 m / s and for this reason the force of the air resistance is negligible and can be assumed $F_W = 0$.

The resistance F_f when moving the robot is determined by the uniform movement of the robot on horizontal terrain (formula 4) (Dimitrov, 1997; Dimitrov, 1975, Velev 1975):

$$F_f = f.G, (4)$$

where f is the drag coefficient of the self-movement;

G - force of gravity of the robot.

The drag coefficient of the self-movement is taken tabularly for the most unfavorable soil conditions (Ivanov, 2006). This is dry sand and the drag coefficient of self-movement is 0,2.

The force of gravity of the robot is determined by the dependence (5):

$$G = g.M_R, (5)$$

where g is the ground acceleration of 9.81 m / s2;

M_R - explotacion mass of the robot.

The total explotacion mass of the robot is defined as the sum of the mass of the frame, the mass of the wheels and the mass of all its parts, as indicated in formula (6) (Dimitrov, 1980):

$$M_R = \sum m_C + \sum m_E \quad , (6)$$

where m_C is the mass of the structure, kg;

m_E - mass of the equipment, kg.

To the mass of the structure belong the following elements:

- Calculated weight of the frame - 11.7 kg. It is determined according to pre-specified dimensions and profile for it. Profile 0.0.026.33 of the company Item industrial Technik GmbH (Item Industraltechnik, 2020) with dimensions hxlxd - 30 00x500 mm was selected;
- The weight of the selected tires is 4x2 kg or 8 kg. The selected tires are manufactured by MITAS, model 4.00-8 43A6 / 31A6 TS-01 2 PR (Ivanov, 2015; Mitas catalog, 2020);
- The mass of the drive motors is 2x7 kg or 14 kg. K-PMDC M.06.03 24V-0.25kW electric motors with worm gearbox CMIS030 (motor reducers) were selected (Spirov, 2016);
- The weight of the motor to steering is 2 kg. VGA60FHH-72i 24V 30 W motor is selected.
- Hubs with rims 3 kg or 12 kg in total. The hubs are designed specifically for the model, and the rims are standard composite and lightweight rims for power tiller with a connecting diameter of 8 "and attachment to the hub with 4 pcs. M10 bolts. The bolt spacing is 72 mm. The wheels are widely used for milling machines Gardenia, Gradina, Bellini, RTR, Premium, Raider, Petrov, etc .;
- Hinge bolts 1,192 kg + 1,253 kg + 1,67 kg. The total mass of the hinges together with the arms for attachment to the frame is 4,115 kg;

The mass of the equipment can be expressed by:

- Battery - 2 pcs. x 17.3 kg, total 36.4 kg. The batteries are BA-6FM55-X with a capacity of 55 Ah, connected in series;
- Additional equipment 10 kg.

For the total mass of the robot according to (5) it is obtained:

$$M_R=11,7+8+14+2+12+4,115+34,6+10= 96,4 \text{ kg}$$

According to the formula (5) for gravity we get:

$$G=9,81.96,4=945,7 \text{ N}$$

The already determined values are replaced in the formula (3) and for the force of resistance we get:

$$F_f=0,2.926=189,1 \text{ N}$$

The sum of the resistance forces during the movement of the robot according to (3) is obtained ΣF_C = 189.1 N. Due to the fact that the robot will not perform heavy tillage and the specifics of its attached equipment for traction resistance can be assumed 80 N. Then for the resistance power according to (2) can be written:

$$Pc=(189,1+80).0,83=223,4 \text{ W}$$

When determining the required power to drive the agricultural robot, the following parameters must be selected according to the a priori information:

of the worm gear drive η = 0.96;

- efficiency of power transmission from the engine of the equipment to the executive unit η_O=0,9;
- power reserve factor r=1,1.

Finally, for the required power to drive the agricultural robot depending on (1) is obtained:

$$P_e=1,1((223,4/0,96)+(250/0,9))$$
$$P_e=561,53 \text{ W}$$

With the power thus determined, the necessary motors for propulsion, control and additional equipment can be finally selected.

The final selection is based on the torque.

It can be expressed as a shoulder force, and for the driving resistance moment it can be written (7):

$$T_R = F_f . r_k, (7)$$

where r_K is the radius of the wheel, m.

Based on the low speed of the robot, it can be assumed that the dynamic radius of the wheel is almost equal to the static one. According to the catalog data for the selected tires, r_K = 0.195 m is assumed.

In this case, for the resistance moment T_R of formula (7) we obtain:

T_R=185,2.0,195=36,14 Nm

The selected drive motors provide torque T = 2.4 Nm and have an output power of 0.25 kW at a current I = 13 A. In this case, to overcome the resistance moment, it is necessary to use worm gearboxes with a gear ratio i = 15. Then for the driving moment we get (8):

T_M=T.i=2,4.15=36 Nm (8)

Of interest is the determination of the time for autonomous operation of the robot (Evtimov, 2015; Evtimov, 2018). It is determined by the dependence (9):

$$t_a = \frac{C_A}{??I}, (9)$$

where C_A is the capacity of the batteries;

ΣI - the sum of the current required to drive the electric motors.

The capacity of the batteries is determined taking into account their serial connection. The capacity of the batteries is preserved and it is C_A = 55Ah.

The amount of the drive current can be determined by the required drive power. It is known that the installation of the robot is 24V and according to standard electrical dependences the required drive current is determined (10):

I=P/U=561,53/24=23,4 A (10)

It is more plausible to determine it according to the selected electric motors for propulsion, control and additional equipment. The sum of the current can be expressed by (11):

$\Sigma I=2.I_M+I_S+I_o$=2.13+3+13=42A, (11)

where I_M is the current of the drive motors;

I_S - the current of the control motor;

I_O - the drive current of the equipment.

It can be seen that there is a certain difference and for the correct sizing of the system we work with larger, peak values. For the time of autonomous work according to (9) is obtained:

t_a=55/42=1,3 h

The obtained time for autonomous work shows that the agricultural robot is able to perform tasks within 1h and 15min. Naturally, this is the most severe mode of operation, which includes all consumers. In practice, however, in this severe mode, the robot does not work 100%. The other time he needs to move to the object of manipulation, refueling of the consumatives and more.

If an additional charge is required, it is possible to install a solar panel to support the operation of the batteries by recharging them during the auxiliary operations of movement or maneuvering, as well as during the active operation. Another option to increase the battery life is to install larger batteries, which can double the capacity from 55 to 100 Ah by increasing their mass from 36,4 to 60,4 kg.

CONCLUSION

The resistance power from the self-movement of an agrorobot is determined. It determines the required power to drive the agricultural robot, powered by electricity. The mass of the robot and the force of resistance to movement are determined.

The necessary driving moments of the power electric motors, necessary for the autonomous movement of the robot, are determined, according to the necessary resistance moment.

The time for autonomous operation of the agricultural robot is determined according to the maximum use of the consumers. This mode of operation does not fill 100% of the working time of the agricultural robot. Guidelines are given to increase the time for autonomous operation of the agricultural robot.

The developed methodology can be applied for subsequent designs of agricultural robots and machines of this type.

ACKNOWLEDGEMENT

The authors are grateful to the Center for Research, Technology Transfer and Intellectual Property Protection at the Agricultural University - Plovdiv for the subcontract on internal project 02-20 "Power unit for agricultural robot".

REFERENCES

Blackmore, B. S., Stout, W., Wang, M., Runov, B., 2005. Robotic agriculture – the future of agricultural mechanisation? 5 th European Conference on Precision Agriculture. ed. J. Stafford, V. The Netherlands, Wageningen Academic Publishers, 621-628.

Celen, I., Onler, E., Kilic, E., 2015. A Design of an Autonomous Agricultural Robot to Navigate between Rows. Proceeding International Conference of Electrical, Automation and Mechanical Engineering (EAME 2015), Atlantis, 349-352.

Dimitrov, Y., Georgiev, P., Morchev, E., Stanimirov, S., 1980. Rakovovdstvo za proektirane, izgrazhdane i izchislyavane na avtomobili, traktori i kari. Technika, Sofia.

Dimitrov, Y. 1997. Traktori – proektirane i izgrazhdane na traktora.Tehnicheski Universitet – Sofia.

Evtimov, I., Ivanov, R., Kadikyanov, G., Staneva, G., 2018. Energy Consumption and CO2 Emissions for Life Cycle of Electric and Conventional Cars.MATEC Web of Conferences, 2018, No 234, 02007, 1-5.

Evtimov, I., Ivanov R., Staneva, G., Kadikyanov, G., 2015. A Study on Electric Bicycle Energy Efficiency. TRANSPORT PROBLEMS, 3, 131-140.

Griepentrog, H. W., Jæger-Hansen, C. L., & Dühring, K., 2012. Electric Agricultural Robot with Multi-Layer- Control. Paper presented at International Conference of Agricultural Engineering, Valencia, Spain

Item Industrialtechnik GmbH., 2020. Acsses on https://bg-product.item24.com/en/productdetails/products/line-8-construction-profiles-1001042794/profile-8-40x40-light-natural-2633/

Ivanov, R., Rusev, R., Ilchev, P., 2006. A laboratory investigation of tyre sliding grip coefficient. Research Journal ”TRANSPORT”, vol. 21, No No 3, Lithuania, 2006, 172-181.

Ivanov R., Georgiev, K., Kadikyanov, G., Staneva, G., 2015. An Experimental Research on the Wear of Truck Tire. TRANSPORT PROBLEMS, 4, 91-98.

Mitas catalog, 2020. Acsses on https://mitas-tyres.com/en/products/agriculture-tyres/tractor-small/ts-01

Pedersen, S. M., Fountas, S., Blackmore, S., 2008. Agricultural Robots — Applications and Economic Perspectives, Service Robot Applications, Yoshihiko Takahashi (Ed.), InTech, Croatia, 369-382.

Sevov A., Yancheva, C., Popova, R., 2012. Impact of Soil and Climatic Conditions in the Plovdiv Region over the Multifoliolate Alfalfa Development. Fifth International Conference on “Water observation and information system for decision support” BALWOIS, 28 May - 2 June Ohrid, Republic of Macedonia.

Spirov, D., Komitov, N., 2016. DSP based induction motor drive with parallel quasi-resonant converter. Proc. XXV International Scientific Conference Electronics – ET 2016, pp. 258-261, Sozopol, 2016.

Velev, N., 1975. Teoria i izchislenia za traktora i avtomobila. Zemizdat, Sofia.

Wilson, J. N., 2000. Guidance of agricultural vehicles - a historical perspective. Computers and Electronics in Agriculture 25, 1-9.