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EVALUATION OF THE THRUST FORCE OF A MULTIROTOR AGRICULTURAL DRONE

Summary

Multirotor drones can be used in ecological agriculture as agricultural machines that do not produce pollution or knead the soil. The movement of drone over plants is related to the thrust generated by rotors and propellers. Test stand, where the drone was placed on electronic scales, was constructed in order to establish the thrust force of the drone. The test stand, where the drone was placed on electronic scales, was constructed in order to establish the thrust force of the drone. Optical tachometer was used to measure the propellers' rotational speed. A mathematical formula was determined that describes the relation between the rotational speed of the drone propellers and the thrust force it generates.

***Key words**: agricultural drone, Unmanned Aerial Vehicle, thrust force, test stand*

OCENA SIŁY CIĄGU WIELOWIRNIKOWEGO DRONA ROLNICZEGO

Streszczenie

Drony wielowirnikowe mogą być wykorzystywane w rolnictwie ekologicznym jako maszyny rolnicze, które nie emitują zanieczyszczeń i nie ugniatają gleby. Ruch drona nad roślinami związany jest z wytwarzaną siłą ciągu przez wirniki i śmigła. W celu wyznaczenia siły ciągu drona zbudowano stanowisko badawcze, w którym dron osadzono na wadze elektronicznej, a do pomiaru prędkości obrotowej śmigieł użyto tachometru optycznego. Wyznaczono formułę matematyczną opisującą zależność pomiędzy prędkością obrotową śmigieł drona a wytwarzaną przez niego siłą ciągu.

***Słowa kluczowe:** dron rolniczy, bezzałogowy statek łatający, siła ciągu, stanowisko badawcze*

1. Introduction

Typical ecological agriculture, that is organic farming, is not only growing plants using natural methods as commonly believed. It is also cultivating fields surrounded or even crossed with natural habitats of plants, shrubs and trees that create proper microclimate and offer shelter to the reach fauna that thrives there. The future of ecological agriculture is closely related to the future of machines specific for such farming. Machines which, when passing over the crops, do not knead the soil, make it possible to carry out procedures on plants in a selective manner, without destroying them. Machines which can move over small fields, autonomously dodging natural obstacles. Machines which, when working in the field, do not pollute the natural environment with fumes from the exhaust pipes of their engines.

Drones – pilotless aircrafts, slowly becoming such machines, are used more and more frequently in agriculture. Multirotor drones are the most popular as they can remain still in the air or move in any direction at a speed independent of the work level or load. They are equipped with cameras and containers with devices distributing seeds and organic plant protection products [5]. Application of drones in ecological agriculture can be justified in the future for economic and environmental reasons.

Drones make it possible to monitor the crops, taking advantage of phenomena related to absorption and reflection of light by plants. Remote sensing on research with RGB and multispectral cameras is currently widely used and developed in agriculture [9]. This technique provides farmers with information on the health condition of the plants. The drones can be also used as robots for performing protective procedures on plants with variable doses of biological protection products, relevant to the plants' healthiness [3].

Drones can also be a promising solution for application of trichogramma biological plant protection product as they make it possible to disperse the product contained in special capsules in a precise and quick way. The air jet generated by rotor drone propellers additionally prevents the capsules from being blown away by side wind which can result in uneven distribution of the product on the field [8].

The capacity of multirotor drones to hang over crops and the possibility of their vertical takeoff and landing are some of its unquestionable advantages. The drone's thrust force is a mechanical force which lifts the drone with the generated air jet. The air jet is created by an engine with propellers. If the thrust force is greater than resistance force, the drone accelerates. In order for the drone to be able to stay airborne, the thrust force must at least counterbalance the gravity force [6].

Electric brushless motors are the principal power transmission system of a multirotor drone. The majority of modern engines is identified with width and height of the motor housing. kV value is usually indicated on the engine. It indicates how many engine revs per minute occur per volt of impressed electric voltage. The value is measured at zero engine load so the actual rotational speed will differ depending on the friction losses and values of the carried load. kV value determines the scale of dependence of rotation on the battery voltage. Higher battery voltage allows the engine to rotate faster. The drone can move upwards and fly in all directions. When all four rotors rotate at the same speed, the drone moves up vertically. In order to fly straight, to the left or right, two rotors rotate faster and the drone tilts in the direction of the flight. To make the drone rotate around vertical axis, two opposite rotors rotate faster [11].

The drone's power transmission system is a group of mechanical and electric systems that generate power and transfer it in a way that creates movement. The propellers also give it the speed required to stay airborne which makes it possible to achieve the desired altitude. A propeller must be adjusted to the utmost possible use of power developed by the engine. When selecting the propeller, its direction, size and pitch need to be taken into consideration. Propellers are available in two different shapes with opposite pitch angles. These two propellers, however, make it possible for the drone to maintain balance and stabilize the aircraft level [10].

The propellers have a hub fixed directly to the motor and at least two blades emerging from the hub. The size is measured in inches from the end to the end of the two-blade propeller, e.g. from 5 to 6 inches (from 12 to 15 cm). The pitch is measured on basis of how far ahead the propeller could move if it crossed a solid body, making a single turn. The greater the pitch, the more air passes through the propeller with each turn. More air being transferred by the propeller results in greater thrust level [12]. Thrust generated by the drone depends not only on the propeller pitch but also on its length and rotational speed. When propellers are exchanged for longer ones or their rotations increase, the thrust increases, too [1]. What is important in case of using a drone for field works are the aerodynamic forces, referring to the work of rotor drone over crops when hovering.

The velocity, acceleration and hovering over crops influence the quality of the operation performed by the drone. Location of the drone and thrust variability that influences the height control, also have significant impact on the quality of the agrotechnical procedure [4].

The air jet from the drone rotors can, in case of spraying, change the jet shape and penetration of the jet drops into the plants' internal structure [2, 3]. Research on thrust of multirotor drones used in agriculture, including ecological farming, are necessary in order to establish the correct parameters of their work so that in the future they can become the perfect platform for performing agrotechnical procedures.

2. Aim of study

The aim of the research was to determine the relation between the rotational speed of all multirotor drone propellers and the thrust it generates. The research involved a drone used for model works examining use of drones for agricultural purposes, including ecological farming.

3. Material and research methods

The stand for examining the drone thrust was constructed for a drone intended for examining phenomena occurring during spraying of plants in laboratory conditions. It was mounted on a frame placed at the height of 4 meters over the laboratory floor level. The stand is presented in Fig. 1. Hexacopter DJI S-900 was the multirotor drone used for the tests and it was equipped with a motor of 500 Wat, 400 kV and 15×5.2inch propellers.

The drone motors were operated using Graupner MZ – 12 station. In order for all of the drone motors to have the same rotations and for all the motors to rotate simultaneously, the navigation system was switched off in the controller, along with the gyroscope and barometer. The propellers' rotational speed was determined using UT-382 optical tachometer (pos. no 7, Fig. 1), mounted on a support beam attached to the drone construction. Data from the tachometer were transferred to a computer using a USB stick.

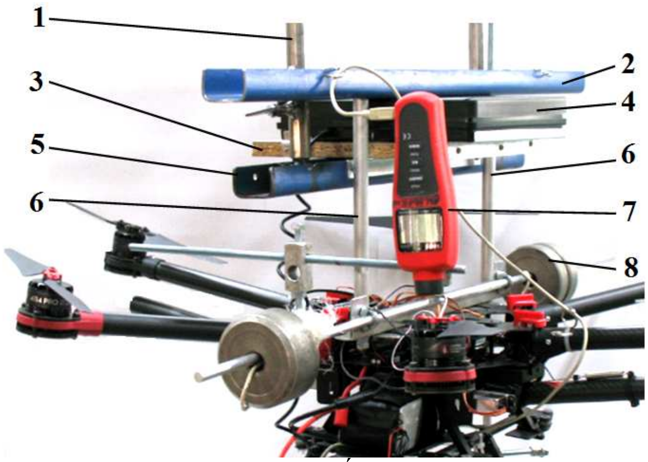

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Fig. 1. Test stand: 1 - table beam hangers, 2 - drone beam, 3 - table, 4 - scales, 5 - beam, 6 - drone beam brackets, 7 - optical tachometer, 8 - weights

Rys. 1. Stanowisko badawcze: 1 - wieszaki belki stołu, 2 - belka drona, 3 - stół, 4 - waga, 5 - belka, 6 - wsporniki belki drona, 7 - tachometr optyczny, 8 - obciążniki

The program included in the meter made it possible to visualize data on the computer screen and save the data in the computer memory using an Excel spreadsheet. The measurement stand is presented in Fig. 2. Steinberg SBS-PT-40/1 electronic scales were used to measure the thrust (pos. no 4, Fig. 1).

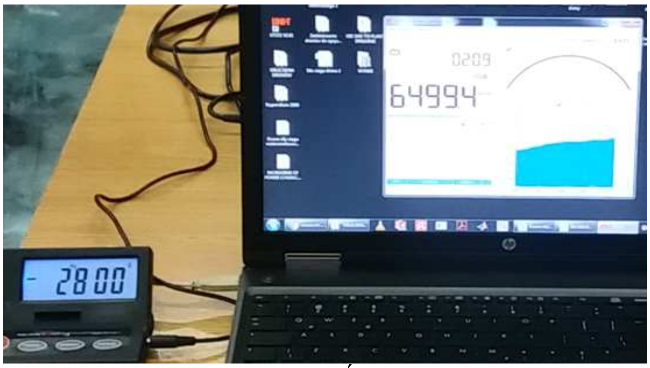

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Fig. 2. Measurement stand

Rys. 2. Stanowisko pomiarowe

The used scales have a separate display, attached to the scales using a cord that also supplies the scales with electric current. The scales were mounted on a table **3**, located on a transverse beam **5**, attached using hangers **1** to the frame. The drone beam was rested on the scales **2**, attached with brackets **6** to the drone frame. The drone was weighed before it was placed on the scales. The weight of the drone with the equipment and battery was 94,35 N. The expected thrust for such a drone with maximum rotations was far greater so to prevent the drone from lifting, weights were attached to it to weigh it down **8**. As a result, the total drone weight was 145,19 N. The scales were switched off and the tare was cleared. As initially the scales indicated value "0", the thrust reading from the display was always negative. The scales display was mounted on a table on which the computer was placed (Fig. 2). This made it possible to observe and read the results off the scales – the drone thrust and the rotational speed off the tachometer.

4. Research results

Thrust measurement results are presented in the diagram in Fig. 3. The diagram presents the relation between the thrust force generated by the drone rotors and the rotational speed of the drone propellers. What was also established on basis of the results was a regression equation which is a mathematical formula that describes the relation between the thrust force and the rotational speed of the propellers.

$$F = 9 \cdot 10^{-7} \cdot n^{2,137} \quad (1)$$

where:
F - thrust force [N],
n - rotation [RPM].

Index of compatibility of the equation and the results $R^2 = 0,9893$.

The observed maximum thrust for the examined drone was 138,9 N with the propellers' rotational speed of 7130 RPM.

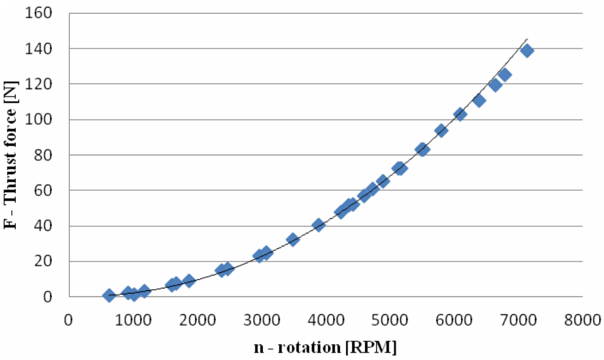

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Fig. 3. The dependence of the drone thrust force on the propellers' rotational speed
Rys. 3. Zależność siły ciagu drona od predkości obrotowej śmigieł

5. Conclusion

The used test stand and measurement methods made it possible to determine the thrust force of the entire drone with all motors working in the scenario of the drone hovering motionlessly over the field surface. The obtained measurement results and the equation established on their basis intended for presenting the dependence of the drone thrust force on the rotational speed of its propellers will be used for further research works.

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