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SYNTHESIS AND STUDY OF AN ENGINE-GENERATOR CONTROL SYSTEM FOR A HYBRID DRONE

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Abstract: The analysis of the existing solutions shows that attempts are being made to transform the power source. Various options of additional energy on board of the UAV are being considered. The most successful for now is the introduction of a hybrid power supply, which uses the energy of the fuel processed into internal combustion engine (ICE) - rotating generator and the energy of the battery. This increases not only the flight time but also the payload of the UAV. For the UAV aviation industry, the hybrid systems are new and unusual object to manage.

Key words: UAVs, power supply, hybridization, increasing flight time

I. INTRODUCTION

Unmanned drones are widely used to solve specific tasks when the use of a manned aircraft is impossible or economically unprofitable, for example: inspection of hard-to-reach zones of the state border; monitoring various areas of land, water surface and underwater; determining the consequences of natural disasters, accidents and catastrophes; detection of forest fires; performing search and other works; etc. The use of Unmanned Aerial Vehicles (UAVs) is suitably possible to improve a certain situation in spatial and hard-to-reach areas with relatively low flight self-sustainability.

The traditional internal combustion engine (ICE)-based UAV propulsion systems suffer from limitations related to transmission weight and reliability, the complexity of the individual rotor control system, and the challenges of carrying fuel on the board. Battery-powered drones have a low capacity-to-weight ratio with relatively little flight time. These reasons reveal the main problem associated with battery inefficiency, namely the heavy weight of batteries and their low electrical capacity. The disadvantage of multicopter UAVs is their limited endurance around 20~30 minutes due to the low energy density of the battery.

Thus the need to study and research the possibility of increasing the flight time while increasing the reliability indicators and increasing the payload. One such possibility is the hybridization of the UAV drive systems.

II. SELECTION OF THE ENGINE-GENERATOR GROUP

The hybrid power supply consists of: gasoline engine with internal combustion; fuel tank; generator; rechargeable batteries; controller. It is designed to provide the system with electric motors - propellers of the copter. A hybrid transforms fuel to generate electrical power. The electricity drives the electric traction motors, charges the backup batteries and powers the on-board systems. The operator has to fill the fuel tank and monitor the battery capacity before taking off again. Therefore, the work is focused on the hybrid system of the ICE -electric generator-battery type. The proposed hybrid drive system consists of:

1. Module for controlling the revolutions of ICE;
2. Engine-generator module for the main power source on board of the copter;
3. Battery module for backup power supply.

In the system thus proposed, the high energy density characteristics of the gasoline engine and the low power density characteristics of the battery are combined. The purpose of the development is to synthesize and research a control system of the engine-generator group, controlling the angular speed of the ICE with feedback on the voltage of the generator.

Fig.1 shows the conceptual functional diagram for the development of a hybrid power supply for a drone. Seen here is a simplified configuration of the proposed fuel-battery hybrid system. The generated electrical power is used to directly power the drive electrical motors, charge the battery on board the UAV and power the on-board consumers.

The advantages of this scheme are that ICE converts the chemical energy of the fuel into mechanical and thermal energy. The usual efficiency of internal combustion engines is around 25%. The internal combustion engine that is available (McCulloch engine 0,25 m^3) and was chosen to drive the generator on board the drone has parameters: Cubic capacity – 0,25 m^3; Maximum torque at 8000 rpm – calculated in (3); Maximum revolutions - 10000 rpm; Maximum power – 0,6 kW at 8000 rpm; Weight 3 kg.

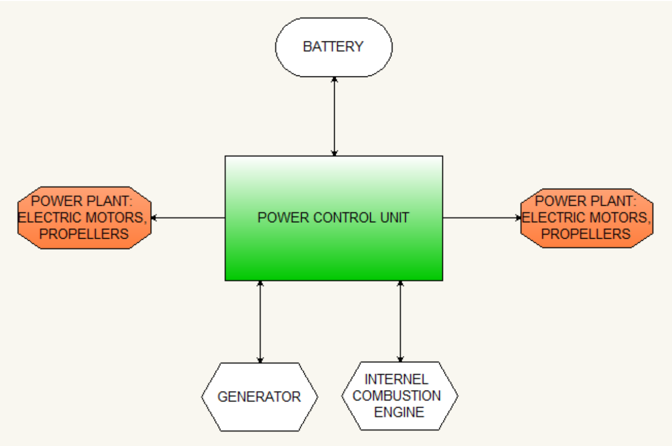

Figure.1 Conceptual functional diagram of the proposed hybrid drone power system

The engine fuel is gasoline. The advantage of gasoline is that it has an energy density of 12 kWh/kg [3,8,9,10,14] and a lithium-ion battery (5200 mAh) has between 90 - 160 Wh/kg [2,4,6,8,11,] energy density. To make a rough estimate of the electrical energy that will be converted from the gasoline, the following ratio is used:

$$\boldsymbol{D = D_{petrol} \,.\, e_{IC} \,.\, e_{gen} = 12 \,.\, 0{,}25 \,.\, 0{,}70 = 2{,}1\ kW\,h/Kg} \qquad (1)$$

where D_{petrol} is the energy density of gasoline; $\mathbf{e_{IC} = 0{,}25}$ is the internal combustion engine efficiency (efficiency); $\mathbf{e_{gen} = 0{,}70}$ is the generator efficiency (efficiency).

Despite the reduction in the energy density of the gasoline engine through thermal and mechanical losses from processing, the calculated energy density is obtained many times higher than that of the battery.

Since the specification of the selected ICE lacks the mechanical characteristic, the torque must be calculated to determine the output current produced by the generator. To calculate the torque, the expression is used:

$$\mathbf{M = (9550 \,.\, N/n) = 9550 \,.\, (0{,}6/8000) = 0{,}71\ Nm} \qquad (2)$$

where **M** is the torque of the ICE; **n** are revolutions of ICE; **N** is the power of the ICE (0,6 Kw) at revolutions - **n** (8000) ;

ICE provides the generator with revolutions and torque. At engine speeds of around 8,000 rpm, this is 0,71 Nm (2). The resistive moment of the generator, as a function of the load, affects the ICE. In this way, the generated current also changes, and from there the received power. The relationship between current and torque is expressed by calculating the torque required to produce 1 A of current.

The motor constant KM (the generator constant KM = ((1/KV) x 30/π) is an indicator of motor sizing as it determines the torque-power relationship. The torque constant defines the torque-current relationship of the motor and is in Nm/A [7,5,12,13,15]:

$$\mathbf{KM = ((1/KV).30/\pi) = =(1/370).30/3{,}14 = 0{,}025\ Nm/A} \qquad (3)$$

where KV is the generator speed constant = 370 rpm/V.

Therefore 0,025 Nm is required to produce 1A current. In this case, expressions (2) and (3) show that 28,4 A of current is obtained from the selected ICE-generator configuration. During the tests conducted with a developed stand and at different loads of the generator, 30A was measured at its output. These results confirm the theoretical conclusions, obtaining the following measurements: 30A current at 8000 rpm on ICE or:

$$\mathbf{M = I \,.\, KM = 30A \times 0{,}025Nm/A = 0{,}75\ Nm} \qquad (4)$$

The ratio between theory and practical experiment is 94,66%, resulting in a 5% relative error. This confirms the conclusions drawn. The main requirements for the generator are: to have a compatible KV parameter with the appropriate revolutions of the internal combustion engine (a suitable KV parameter means that the generator will generate the desired voltage in the best operating range of the ICE).

A hybrid generator system provides a power source from an electro-hybrid generator. The hybrid generator system is used to overcome the weight of the UAV. When a hybrid generator system is used for UAVs, the following conditions must be met for effective and efficient operation of the UAV:

1. The total continuous power (W) may be greater than the power required to maintain the flight of the UAV;
2. The power required to make a UAV flight is a function of the total weight of the UAV, which includes the total weight of the hybrid electric generator, the total weight of the fuel and the total weight of the payload:

$$\boldsymbol{G_{bla} = G_{gen.group} + G_{fuel} + G_{pol.load}} \qquad (5)$$

The regulation of the voltage of the electric generator is carried out by regulating the revolutions of the driving ICE by means of feedback. It measures the output voltage of the electric generator and the PID controller with an actuator - a servomechanism is connected to the throttle of the ICE.

III. CONTROL OF THE PRODUCED VOLTAGE OF THE GENERATOR

The proposed system for controlling the output voltage of the generator through the revolutions of the ICE includes:

- A system for controlling the revolutions of the ICE, driving an alternating current (AC) generator;
- Feedback controller with a proportional, integral, differential derivative (PID - regulator) algorithm;
- -AC generator, which is through a three-phase Ilarionov rectifier, supplies the DC bus on board the drone.

The purpose of the development is to keep the DC voltage within the prescribed limits in the Speed Controllers specifications of the drone's drive motors. For this purpose, it is necessary to synthesize a regulator by which to control the throttle of the ICE based on the measured output voltage of the generator. The requirement for the regulation system is to measure the voltage of the DC bus and ensure the condition of its invariance.

The input of the PID controller is the formed error signal between the measured and the set voltage, and the output is the sum of three values, each multiplied by its factor[1]:

$$Output=P*K_P+I*K_I+D*K_D \quad (6)$$

After that, the obtained output signal is transformed into a control signal, which is fed to the actuator mechanism driving the throttle of the ICE. The construction of the ICE engine speed control system is shown in Fig. 2.

The coefficients of the PID regulator are set experimentally, by using the Serial Monitor function in the Arduino IDE (Fig. 3).

The mean of the Legend on Fig. 3 is:

- Green graphic - the set/desired/ voltage that has to be maintained by the motor-generator.
- Blue graph - input variable that has to be kept close to the desired set point.
- Red graphic - regulation of the output, signal to control the servo motor.

Figure 2. *ICE throttle control*

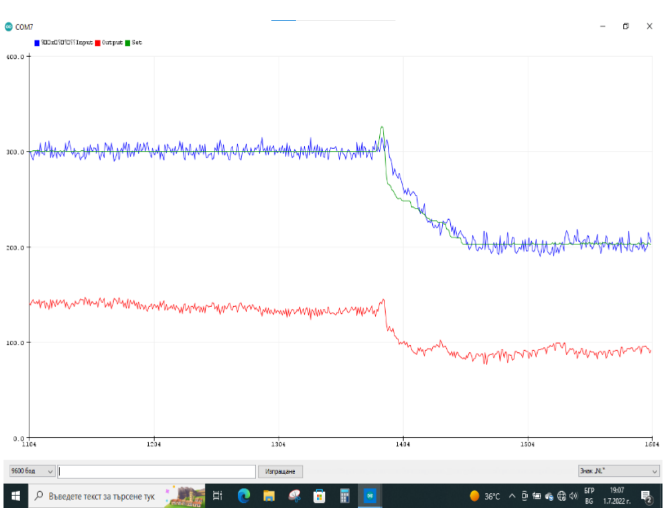

Figure 3 *Diagram of the operation of the ICE throttle valve*

IV. THE CONTROLLER OPERATION ALGORITHM

An algorithm was developed for the operation of the controller. This algorithm is shown in Fig. 4.

In Fig. 5 shows the scheme of the experimental setup for studying the operation of the controller and selecting the coefficients of the regulator.

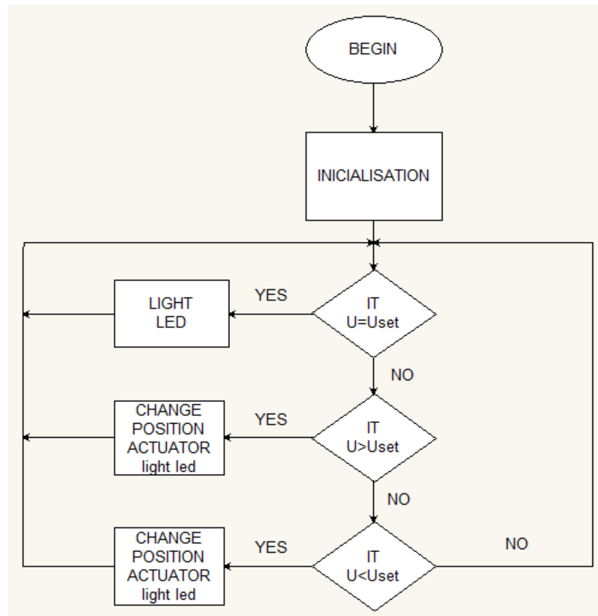

Figure 4 *Controller operation algorithm*

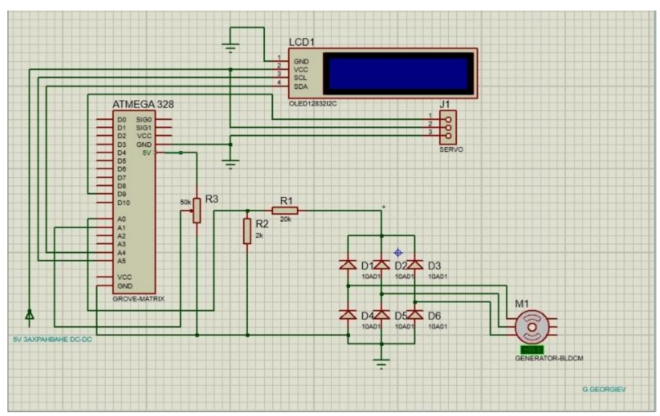

Figure 5 *Synthesis and Study of the regulator hardware*

Figure 6 *Display set up readings during the system during its development*

V. CONCLUSION

1. A hybrid scheme for power supply on board the UAV has been developed.
2. Suitable ICE, generator and controller are selected.
3. An algorithm for system operation has been developed.
4. The regulator coefficients are set experimentally.

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