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OVERVIEW OF POWER PLANTS FOR UNMANNED AIRCRAFT SYSTEMS

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Abstract. This article is devoted to general overview of nowadays existent power plants intended for use in unmanned aircraft systems and types of fuel or sources of energy that can be used in power plants using open source of information.

Keywords: electric motor; internal combustion engine; hybrid-electric power plant; power plant; unmanned aerial vehicle

1. Introduction

Unmanned aviation is one of the most actual and perspective branch of modern aviation. This is due to number of advantages of unmanned aerial vehicles (UAV) over piloted aircraft and development of microprocessor system, navigation, control system, etc.

According to ICAO Circular №328 unmanned aerial vehicles is aircraft which operate without pilot on board. UAV can be divided into autonomous (an unmanned aircraft that does not allow pilot intervention in the management of the flight) and remotely piloted aircraft (An aircraft where the flying pilot is not on board the aircraft). [2]

The main feature of unmanned aviation is absence of flight crew on board of aircraft. This feature gives such main advantages as:

- Relative increase of target load and amount of fuel due to absence of flight crew and life support systems не збільшення цільового навантаження та запасу.
- Increase of working load and reduce influence of human factor. [1]

Capabilities of UAV determine wide range of application of this type of aircraft in different spheres of activities (photography and video filming, real-time surveillance, cartography, military application, etc). The field of application defines requirements for performances of UAV and accordingly requirements for features of power plant.

The main aim of this article is general overview of existent types of power plants, energy sources and fuels intended for unmanned aircraft, their classification and analysis of each type.

2. Classification of power plants for unmanned aerial vehicle

Using classification of engines by fuel type of energy source we may determined 3 basic types of engine for UAV such as:

- Electric motor
- Internal combustion engines (ICE)
- Hybrid-electric propulsion system

Each type has own drawbacks and advantages, and therefore decision about installation of certain type of power plant is made according to purposes and tasks of UAV and payload.

2.1. Electrical propulsion system for unmanned aerial vehicle

For unmanned aircraft with small take-off mass and low velocity it is appropriate to use electric propulsion system. Despite the fact that mass of battery does not change during flight (in comparison with fuel) electric power plant has such advantages:

- Simplicity in maintenance that is only in accuracy of exploitation of storage.
- Sure start without additional means and stable work on transient states.
- Easy automation of operation and control of main parameters of electric power plant such as rotation frequency, supply voltage, current, control of battery charge store. [1]

In general main components of electric power plant are battery, electronic speed controller and electric motor (Fig. 1a). When choosing the last one gives priority to brushless electric motor because it has such number of advantages:

- Long life span
- Low maintenance
- High efficiency [3]

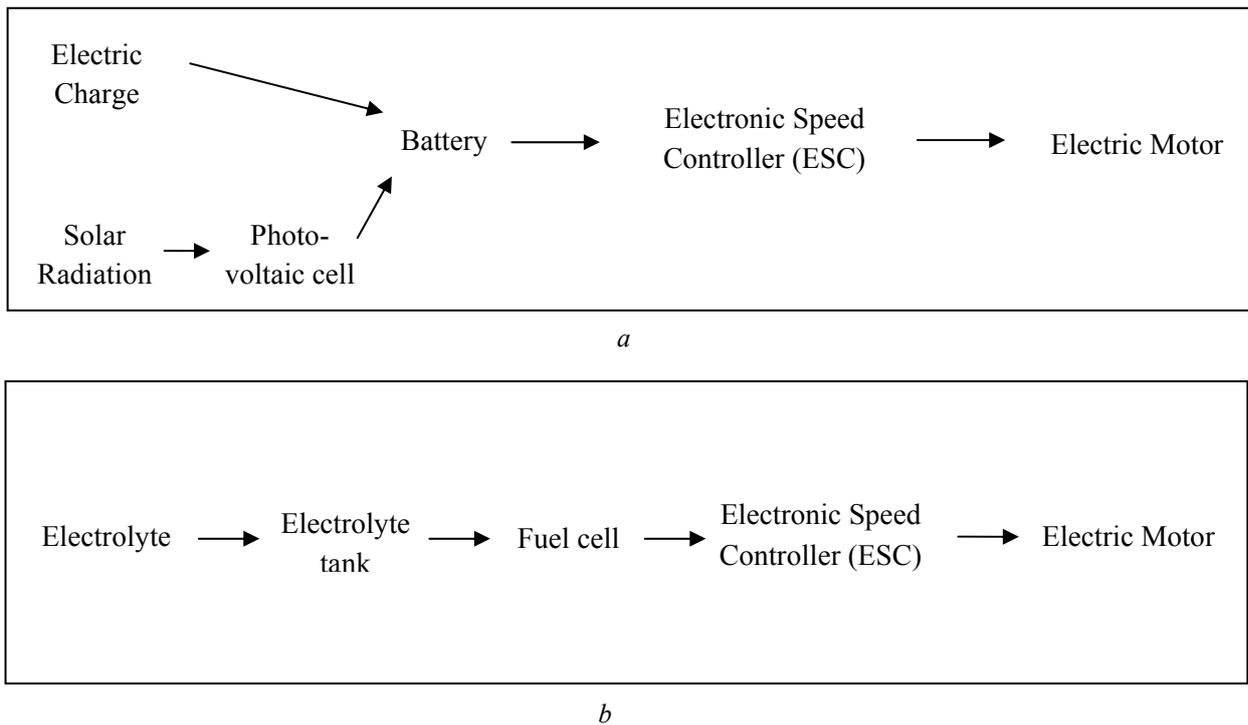


Fig. 1. General structure of electrical power plant for UAV: a) with rechargeable battery; b) with fuel cell;

Rechargeable battery or fuel cell is source of energy for UAV. Differentiate such type of energy source for unmanned aircraft:

- Lithium-ion polymer battery
- Nickel metal-hydride battery (nickel-cadmium battery)
- Hydrogen-oxygen fuel cell
- Supercapacitor (Ultracapacitor)
- Photo-voltaic cell (solar cell) [4, 5]

The most wide spread battery is lithium-ion polymer battery due to high energy density, low self-discharge and simplicity in maintenance.

Another perspective energy source is photovoltaic cells which have high energy density and long live span. But application of such energy source has some disadvantages: energy produced by photovoltaic cell is function of geographical location (longitude, latitude and elevation), time of year, atmospheric absorption and efficiency of given solar cells. [4]

With increasing of flight endurance of UAV it is more appropriate to use energy sources based on hydrogen-oxygen fuel cell or combination of lithium-ion polymer battery with photovoltaic cells. Such decision allows to provide approximately

20-24 hour duration of flight for UAV with mass 10-20 kg.

Application of power plants with fuel cell introduces changes in structure of propulsion system: electrolyte tank serves as battery, fuel cell converts chemical energy into electrical one (Fig. 1b).

2.2. Power plants for unmanned aircraft based on internal combustion engine

Application of electric power plant for unmanned vehicle with great take-off mass and range of flight is ineffective, therefore for such types of UAV can be used internal combustion engines. The main features of internal combustion engine are decreasing of fuel mass during flight and receipt greater power in comparison with electric propulsion system.

Distinguish such types of internal combustion engine that are used in UAV:

- Reciprocating
- Wankel engine (rotary engine)
- Gas turbine
- Jet

Power plant based on ICE for UAV is chose in accordance with advantages and disadvantages of each type of internal combustion engine.

Reciprocating engines are divided into three groups according to number of strokes: two-stroke, four-stroke and six-stroke. Two-piston engines are widely used due to high power-to-weight ratio and small mass. Disadvantages of such type of engine are high level of noise and lower economy in comparison with four-stroke engine.

Six-stroke engine is internal combustion engine based in four-stroke engine but with additional complexity in order to increase efficiency and reduce emissions.[6] Such type of engine is tested in automobile industry and is regarded for usage in unmanned aviation. [5]

Rotary engines are increasingly being used in UAV. This is due to number of advantages that have Wankel engines over reciprocating. Application of rotor leads to decrease in number of details and accordingly to reduce of sizes and mass of power plant. Advantages of Wankel engine include also high power-to-weight ratio, high dynamic characteristics and low level of vibration. Drawbacks of this engine type are high fuel consumption, propensity to overheating and high demands to geometrical accuracy of engine details construction which complicate overall process of engine production.

Owing to high power density and low mass gas turbine engines gained wide usage as aviation engines and auxiliary power plant. Gas turbine engines can be divided into such general types:

- Turbojet engines (are designed to produce thrust from a high-velocity jet);
- Turboshaft engines (produce power in an output shaft, which can drive propeller or helicopter rotor to provide thrust);
- Turbofan engines (mixture of turbojet and turboshaft engines);
- Turboprop engines (use energy created by engine to drive external propeller of aircraft);

Striking example of UAV using gas turbine power plants is RQ-4 Global Hawk (turbofan engine) and General Atomics MQ-9 Reaper (turboprop engine). Choice of such propulsion system is conditioned by sizes of UAV that requires application of more powerful power units.[7]

For UAV of middle and small range application of gas turbine engines is ineffective due to bad fuel economy for small sizes.

Jet engines become more viable option for unmanned aircraft with development of micro-engineering and hydrodynamics. Nowadays exist jet engines with the mass approximately 1.4–2.3 kg, e.g. AT-400 (Fig. 2). Disadvantages of such engines are relative high price and cost of service which also requires professional skills.

Any aircraft engine is designed for specific type of fuel using which it produce optimal characteristics. Differentiate two types of aviation fuel: aviation gasoline (avgas) and jet fuel (aviation turbine fuel ATF). Usually avgas is used for reciprocating or rotary engines and jet fuel – for gas turbine and jet engines. The difference between this two types consist in fact that aviation gasoline is more volatile and extremely flammable, with low flash point in comparison with jet fuel. [9]



Diameter	120 mm
Length	270 mm
Engine weight	2300 g
Thrust	170 N
Maximum rpm	112,000
Mass flow	410 g/sec
Maximum exhaust gas temperature	710 °C
Fuel	Kerosene, Paraffin, Jet A1, White Spirit

Fig. 2. Jet engine type AT-400[8]

2.3. Hybrid-electrical power plants for unmanned aerial vehicle

Hybrid power plant is power plant consisting of at least two separate sources of energy transformation in vehicle that lead to general final output. [10] Hybrid-electrical propulsion system (combination of internal combustion engine and electric motor) is widely used in railway and automobile transport and gain vogue in unmanned aircraft systems. The main advantages of hybrid-electrical power plants are low level of pollution, noise and heat release. In last

years development of hybrid-electrical units became one of the main tasks for military industry in order to improve UAV endurance of flight, energy efficiency and stealth operation.[11]

Distinguish three main configurations of hybrid-electrical power plants:

- Series
- Parallel
- Series-parallel

In series configuration (Fig. 3) mechanical energy of internal combustion engine converts into electrical using generator. This is used in order to provide energy for electromotor or to charge battery.

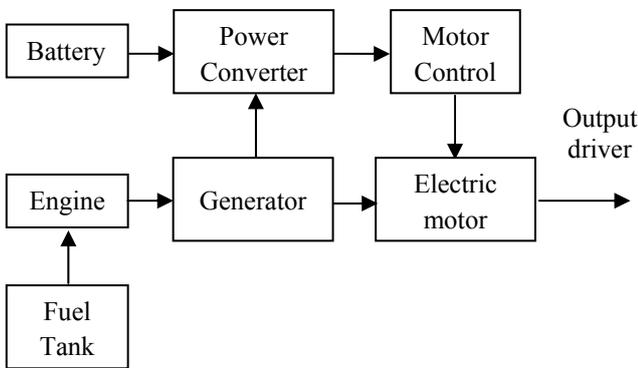


Fig. 3. Series hybrid-electric configuration

Separation of internal combustion engine from thrust creation allows it to operate in optimal operational mode. Because electromotor provide full thrust power this leads to increase of it mass and accordingly to increase of total mass of construction. [12]

In parallel configuration thrust is created either by electromotor or internal combustion engine or by their combination (Fig. 4). [10]

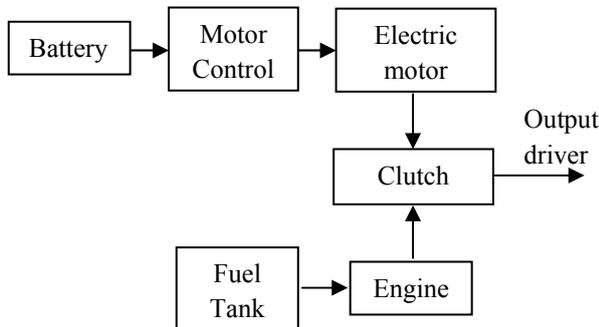


Fig. 4. Parallel hybrid-electric configuration

Since thrust is created by electric motor and internal combustion engine together both engines

can be smaller in sizes than in isolated system. Drawback of such configuration is additional mass of mechanical coupling and more complicated power plant control system. [12]

Series-parallel configuration is a combination of series and parallel configurations (Fig. 5).

Since electromotor, internal combustion engine and generator is connected by planetary gear the distribution of loads is more flexible that allows engines to operate in more efficient modes.

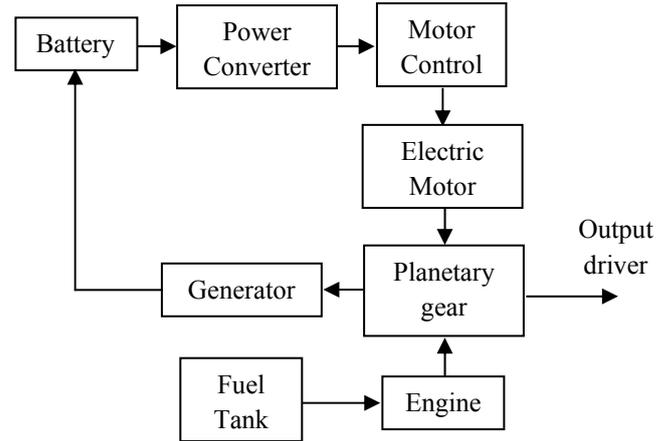


Fig. 5. Series-parallel hybrid-electric configuration

3. Conclusion

Each type of power plants described above has own advantaged and disadvantages that predetermined choice of propulsion system for solving of certain aims and tasks delivered to UAV. The main criteria of power plant selection are power, weight and efficiency which are necessary for providing of concrete given requirements for endurance of flight, range of flight and mass of payload.

Main advantages of internal combustion engine are greater receipt of power in comparison with electric power plant and decreasing mass of fuel during flight. But application of such engine type leads to increase in weight of power plant and in level of noise and pollution.

Depending on the type of storage battery or fuel cell the parameters of electric propulsion system can considerably vary (Table 1). We expected appearance of new types of energy source and storage mediums that will be able to provide increasing demands for power plants of UAV.

We think that one of the most perspective method of improving of UAV characteristics (duration and range of flight) is application of hybrid-electrical

power plant (ICE in combination with electric motor). But benefits and potential of hybrid-electrical power plants in improving of efficiency and

Table 1. Types of energy source for different UAV requirements [4]

Type of power source	Flight duration (h)	Power source mass (kg)	Required power (W)
PV/Li-Po	2	5	40
Li-Po/FC	10	4	20
FC/PV-Li-Po	12	10	150
PV-Li-Po	21	10	200
FC/PV-Li-Po	24	20	200

PV – Photo-Voltaic

Li-Po – Lithium-polymer

FC – Fuel Cell

References

[1] *Poroshkin K.V., N.S. Senuishkin, R.R. Yamaliev* “Peculiarities of power plant design for unmanned aerial vehicle”, *Molodoi uchenyi*, 2011, №3 T.1, pp. 85–88. (in Russian)

[2] ICAO Circular №328, Unmanned Aircraft System, Montreal, 2011, http://www.icao.int/Meetings/UAS/Documents/Circular%20328_en.pdf

[3] *Mohamed M. K.*, “Design and Control of UAV Systems: A Tri-Rotor UAV Case Study”, The University of Manchester, 2012, p. 56.

[4] *Meyer J., Plessis F. and Clarke W.*, “Design Considerations for Long Endurance Unmanned Aerial Vehicles”, *Aerial Vehicles*, Thanh Mung Lam (Ed.), ISBN: 978-953-7619-41-1, InTech, 2009, pp. 445–450.

productivity for UAV should be investigated in the near future.

[5] *Ravi A.*, “UAV Power Plant Performance Evaluation”, Oklahoma State University, 2010, pp.1–41.

[6] *Lukman Nul-Hakem Bin Mohd Yusop*, “Experimental Study of Six- Stroke Engine For Heat Recovery”, University Malaysia Pahang, 2012, pp. 11–12.

[7] *Austin R.*, “Unmanned aircraft systems. UAVs design, development and deployment”, CPI Antony Rowe, Wiltshire, UK, 2010, pp. 102–105.

[8] *Füleky A.*, “Driving systems of unmanned air vehicles”, Miklós Zrínyi National Defense University, Budapest, Hungary, 2005, pp.:669 – 670.

[9] “Aviation Maintenance Technical Handbook – Airframe, Volume 2”, Federal Aviation Administration, 2012, pp. 14–7.

[10] *Glasscock R. R.*, “Design, Modeling and Measurement of Hybrid Power plant for Unmanned Aerial Vehicles (UAVs)”, Queensland University of Technology, 2013, pp. 14–16.

[11] *Lieh J., Spahr E., Behbahani A., Hoying J.*, “Design of Hybrid Propulsion Systems for Unmanned Aerial Vehicles”, 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, 2011, pp. 1–3.

[12] *Schömann J.*, “Hybrid-Electric Propulsion Systems for Small Unmanned Aircraft”, Technische Universität München, 2014, pp. 7–10.

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Ключові слова: безпілотний літальний апарат; гібридно-електрична силова установка; двигун внутрішнього згорання; електромотор; силова установка.

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С помощью открытых источников информации сделан общий обзор существующих на сегодняшний день силовых установок предназначенных для использования в беспилотных авиационных системах, типов топлива и источников энергии, которые могут использоваться в силовых установках.

Ключевые слова: беспилотный летательный аппарат; гибридно-электрическая силовая установка; двигатель внутреннего сгорания; силовая установка; электромотор

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