Densely-Packed Construction for Hybrid Power Control System for Unmanned Aerial Vehicles

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Abstract. This paper examines the creation of the hybrid power control system with dense layout of units for the various vehicles. The relevance of the topic is proved by the several publications of Toyota Motors, Subaru Corporation, Texas Instruments and others, who have implemented similar decisions in their electronic control units. The mathematical model and the developed prototype are suitable for gasoline internal combustion engine, where the main feature of this development is the support and control of energy generation. Due to the dense layout of particular vehicles it is necessary to resolve the issues of electromagnetic compatibility, based on protection and decoupling of various elements among themselves. The controlling device for the internal combustion engine of vehicle carries out a complete decoupling of control and signal circuits, and protection of power for integrated circuits. These constructive decisions include the installation of optically decoupled devices, protective diodes and resistances for bypassing the high voltage surges. The proposed concept includes the control of the engine cooling, ignition, engine rate and throttle, generation current, engine startup and cut-off. The prototype working on this concept has an increased uptime and working distance. These features ensure the stability of the engine and its primary characteristics of rate support and generation current control. Processes of installation prototype modeling, technical decisions and reliability issues have been described. This work can be used to develop the engine control units with high reliability and diverse set of functions.

1. Introduction

Modern unmanned aerial vehicles (UAVs) still do not have a single solution for the flight over long distances or with a long duration of the flight itself. The reason for this is a low energy efficiency of even the most advanced batteries.

One solution is to use an internal combustion engine on gasoline or nitromethane as a part of the aircraft. The engine can be used as a main source of thrust, or as a hybrid power system with a battery.
Such an installation needs a special control unit that monitors this engine and maintains all the parameters of energy generation.

The engine control unit is used as part of an unmanned aerial vehicle as an electronic signal-generating device for an internal combustion engine (ICE) start and correct operation of it while using as a generator. Both carburetor and injector intake systems can be used. The unit solves the tasks of controlling the throttle, cooling the engine, measuring the engine speed, the level of remaining fuel, the temperatures of the engine and the generator. One of the functions also allows you to cut off the ignition and stop the engine. Additional functions of the unit are the measurement of the current consumption of the device and the current of the generator, as well as the voltage of aircraft.

Inside the unmanned aerial vehicle, the location of the unit is carried out in a dense arrangement with other radio-electronic devices that may adversely affect the performance of the device and the quality of the process of its operation. Therefore, when developing circuit solutions, it is necessary to take into account the conditions in which the electronic components are located.

2. Modeling

While developing the device, a model was created that describes the physical processes in the internal combustion engine and its control system. The simulation was performed in MATLAB Simulink. The engine model is based on the example project from this software. It takes into account both the physical and mechanical characteristics of the engine. The project has a throttle control unit, a fuel intake submodel, a combustion and a mechanical submodel. The throttle valve control unit was replaced with a simulated device, and a submodule was added to recalculate the mechanical torque to the generation current. The structural diagram of the model is presented in Figure 1.

![Figure 1. Model structural diagram.](image)

The main purpose of the simulation is to check the operability of the algorithm of the unit, based on adjusting the throttle angle and the torque applied to the engine - the current load equivalent. The main results of the simulation are two flowcharts responsible for generating energy and cooling the engine.

The power generation submodule is a physical model of an internal combustion engine with a maintenance block, which is a simulated device. The input parameter of the circuit is the current consumption of the UAV. Output parameters are the generator current and engine speed.

The temperature maintenance unit simulates the operation of the cooling impeller in the presence of a significant heat flux during operation of the internal combustion engine.

The obtained characteristics of the transients of the hybrid installation during takeoff of the UAV and exit to the operating mode are presented in Fig.2.
3. Device schematic development

The electrical circuit diagram of the unit was designed on a modern electronic base using various protective solutions. The dense arrangement of products within the final vehicle, where the unit can be used, also requires a reduction in its total dimensions.

The control unit of the internal combustion engine is next to other devices, including radio transmitters. In this case, the length of the wires from the device to the sensors and paired devices can be 1.5 meters or more. The onboard radio modem can be located in the close proximity to the modelled unit. In addition, under operating conditions, critical situations may happen when the voltage applied to
the unit is much higher than what is permitted, and the device must withstand such loads for some time (not more than a second). Most often, the excess of the supply and signal voltages is caused by the operation of the high-voltage ignition unit.

To protect the device from electromagnetic interference, surge voltage and other adverse effects from other electronic components, special circuit solutions are provided.

The device uses decoupling methods with the HCPL0600 optocouplers to communicate with other digital devices. This allows you to completely eliminate the connection of the microcontroller directly with the secondary devices of the ICE binding. In addition, the installation of optocouplers provides an increased level of load capacity of the output stages, because of used optocoupler transistors, connected according to the scheme with a common collector. A typical element of optical isolation is presented in Figure 5.

![Figure 5. Optocoupler protection.](image)

The traditional solution for the protection of electronic devices is the installation of protective diodes (suppressors) and the use of blocking capacitors. Protective diodes with a high speed are used. These semiconductor devices are installed on the supply circuits in +3.3V and +5V. Tantalum electrolytic capacitors are used as blocking capacitors, since this type is not susceptible to drying out the electrolyte and has smaller dimensions. Also it is more suitable for surface mounting.

The use of protective resistances in analog and digital circuits is made for the purpose of emergency protection of the microcontroller and peripherals. With a significant increase in voltage on these circuits, the maximum current to the ports of the microcontroller will not exceed the maximum operating values, and the voltage on it will not grow to an unacceptable. This solution is used on the temperature sensor circuits, on the unit’s UART telemetry channel and on the optocoupler control circuits.

In analog circuits, zener diodes are used to protect the ADC voltage. The main analog circuits on the device are two external temperature sensors. Their analog circuits are protected by zener diodes at +5V, and the maximum signal level is +3.3V. An overvoltage Zener diode is installed to minimize distortion introduced into the readings. The protective solution for the temperature channel is shown in Figure 6.

![Figure 6. Analog circuit protection.](image)

For special tasks and for use in the conditions of electronic warfare, special decoupling modules have been developed using fiber optic transmitters. Modules support UART, CAN and RC-PWM communication signals.
These measures, as well as the overall shielding of wires and equipment housings, help to protect the microcontroller from high-voltage emissions from the ignition module, radio transmitting devices in close proximity to the unit, inductive noise and small power surges.

4. Failsafe modes
The device handles emergency situations (in the case of, i.e., loss of communication with sensors.)

When the engine is running, it is possible that the signal about the engine speed disappears. At the same time, if you do not control this frequency, it is impossible to stabilize the charging current with high accuracy. In addition, high engine speed can lead to its rapid breakdown. So, in the absence of this information on the module the ignition is turned off after 5 seconds, and the engine stops.

The module peripheral devices include temperature sensors in a metal flask case. Overheating of the temperature sensor above 200 °C leads to the melting of the lead wires. Damage to the wires leads either to an open circuit temperature measurement, ether to short circuit of this circuit. The second channel of temperature measurement can be connected to the generator, or any other peripheral device. The loss of the signal on the temperature of the internal combustion engine leads to a signal to turn on the cooling impeller to the maximum allowed power to prevent overheating of an expensive internal combustion engine. If the generator temperature data is lost, the engine is stopped by turning off the ignition.

If it is impossible to start the engine, it is difficult to measure the rotational speed, and the engine stops.

There may be an experience of using the module with the internal combustion engine, when the engine is running, but there is no generation current. But the signal transmitted by the current sensor will indicate zero or low current generation, and the staff servicing the unmanned vehicle can independently decide on stopping the engine through software. All these algorithms, as well as the part given in the simulation section, are implemented in the device as its firmware.

5. Device prototype
The prototype of the device is an electronics module in the form factor of the Raspberry Pi computer (for ease of connection). It has all the previously described protective solutions, contains 8 input and output channels and two supply voltages. One power source is used for the microcontroller, and the second - for the peripheral connection channels. This electronic unit controls the electric motor, engine cooling, the servo drive of the throttle valve, the electronic control unit of the starter, the tachometer, the ignition disconnect unit (Kill-switch), the fuel level sensor is connected to the unit. 2 channels of the device remain unused.

The development uses the STM32F105RCT6 [4] microcontroller of ST Microelectronics.

Figure 7. Device printed circuit board.
Device supports communication via USB, UART and CAN. The main data channel from the device is CAN, which is differential. This choice is due to increased noise immunity, as the SN65HVD232 differential transceivers are used. It should be taken in account, that using USB for on-board devices is not recommended. Due to vibration levels, the contact between the plug and socket of USB is not reliable, and may lead to the bus malfunction, which causes port re-enumeration and data loss.

Telemetry data enters the on-board computer, which performs the full cycle of UAV control with the help of this unit.

The developed technical solution was released and tested on a small series. It is implemented on unmanned tiltrotor aircrafts.

6. Conclusion

The use of the generator with ICE made it possible to increase the flight duration for UAV from 20 minutes to 1-1.5 hours, depending on the volume of the fuel tank. Such a control unit, providing optimal operation of the engine and generator, allows you to maintain the normal life of the battery and the internal combustion engine.

The engine control unit can be used both to control the hybrid generator set, and to control the internal combustion engine, which in some cases can be the main engine of the mobile vehicle.

The use of the developed engine control unit and the protective solutions is not limited to unmanned aircraft, and potentially can be used in light aircraft, vehicles and mobile wheeled robots. The use of the device in heavy aircraft will require additional studies on the reliability of the unit, in particular, decisions will be needed to ensure its redundancy.

7. References

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