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THE CONCEPT OF ELECTRONIC CONTROL UNIT FOR COMBUSTION ENGINE IN HYBRID TANDEM

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Abstract. *The article presents the concept of a hybrid propulsion unit for ultralight aircraft. A combustion unit and an electric motor/generator were presented. As part of the research, a dedicated combustion engine controller and a two-way converter for energy conversion were built. The prototype drive unit was installed on a test stand and its initial characteristics were determined. The results of research and conclusions related to the construction of a hybrid drive unit are presented.*

Keywords: combustion engine, axial motor-generator, engine controller, hybrid engine

KONCEPCJA ELEKTRONICZNEJ JEDNOSTKI STERUJĄCEJ SILNIKA SPALINOWEGO W ZESPOLE HYBRYDOWYM

Streszczenie. *W artukule przedstawiona została koncepcja hybrydowej jednostki napędowej dla ultralekkich statków powietrznych. Przedstawione zostały jednostka spalinowa a także silnik/generator elektryczny. W ramach badań zbudowany został dedykowany sterownik silnika spalinowego i dwukierunkowa przetwornica do konwersji energii. Prototypowy zespół napędowy zabudowano na stanowisku badawczym i wyznaczono jego wstępne charakterystyki. Przedstawiono wyniki badań i wnioski związane z budową hybrydowej jednostki napędowej.*

Słowa kluczowe: silnik spalinowy, zespół silnik-generator, kontroler silnika, zespół hybrydowy

Introduction

The latest proposals of the European Commission as part of the Fit for 55 package include: taxation of aviation fuel, which has so far been exempt from fees, the withdrawal of free CO_2 emission allowances and a greater share in driving with low-emission fuels [2, 3]. An alternative to traditional propulsion could be synthetic fuels or biofuels.

Electric or hybrid aircraft may also become the future of aviation. Hybrid drives in the aviation industry are a novelty that gives the possibility of environmentally friendly flights with less noise.

The hybrid connection of a gasoline combustion engine and an electrical motor offers numerous advantages, which make it an ideal solution for fuel-efficient and environmentally-friendly appllications. Some of the major advantages are shown below:

1. Fuel Efficiency: The hybrid connection provides improved fuel efficiency by utilizing the electric motor during low-speed and light-load conditions. This results in significant fuel savings and reduced emissions.
2. Performance: The hybrid connection provides improved performance by utilizing the electric motor to assist the gasoline engine during high-speed and heavy-load conditions. This results in improved acceleration and better handling.
3. Regenerative Braking: The hybrid connection utilizes regenerative braking, which converts the kinetic energy into electrical energy during braking. This energy is stored in the battery pack and can be utilized to power the electric motor.
4. Reduced Emissions: The hybrid connection reduces emissions by utilizing the electric motor during low-speed and light-load conditions. This results in reduced emissions of greenhouse gases and other pollutants.

The future of hybrid electric aircraft in aviation is promising, as the industry seeks to reduce emissions and fuel consumption, while maintaining safety and performance standards.

1. Hybrid connection of gasoline combustion engine and electrical motor

The hybrid connection of a gasoline combustion engine and an electrical motor can be achieved through different methods. The most common approach is through a series-parallel hybrid system, which utilizes both series and parallel configurations to optimize the performance of the powertrain. In this system, the gasoline engine is coupled with an electric motor, which is powered by a battery pack. The battery pack provides additional power to the electric motor, which in turn assists the gasoline engine during acceleration or high load conditions.

During low-speed and light-load conditions, the gasoline engine can be turned off, and the vehicle can operate solely on the electric motor. This is known as the electric-only mode, which provides a significant reduction in fuel consumption and emissions. On the other hand, during high-speed and heavy-load conditions, the gasoline engine is turned on, and the electric motor assists the engine to provide additional power. This is known as the hybrid mode, which optimizes the performance of the powertrain and provides improved fuel efficiency.

1.1. Serial hybrid system

A serial hybrid system, also known as a range-extended electrical device (REED), utilizes an electric motor as the primary source of power and a gasoline engine as a secondary source of power. In a serial hybrid system, the gasoline engine does not drive the machine directly, but instead, it is used to generate electricity, which powers the electric motor. The electric motor provides the majority of the mechanical power, while the gasoline engine is used only to recharge the battery or to provide additional power when needed.

The serial hybrid system offers several advantages, such as improved fuel efficiency, reduced emissions, and improved performance. The electric motor provides the majority of the power needed to drive machine, which results in improved fuel efficiency and reduced emissions. The gasoline engine is only used to recharge the battery or to provide additional power when needed, which further improves fuel efficiency and reduces emissions. The serial hybrid system also offers improved performance, as the electric motor provides instant torque, which results in improved acceleration and better handling.

One limitation of the serial hybrid system is the cost of the battery and electric motor. The battery and electric motor are more expensive than a gasoline engine, which results in a higher cost for the vehicle. The serial hybrid system also has limited electric-only range, as the battery is only used to power the electric motor and not to drive the wheels directly [3].

1.2. Parallel hybrid system

A parallel hybrid system utilizes both a gasoline engine and an electric motor to drive the wheels directly. In a parallel hybrid system, the gasoline engine and the electric motor are connected to the same transmission and can work together or independently to provide power to the receiver. The gasoline engine provides power during high-speed and heavy-load conditions, while the electric motor provides power during low-speed and light-load conditions.

The parallel hybrid system offers several advantages, such as improved fuel efficiency, improved performance, and regenerative braking. The electric motor provides power during low-speed and light-load conditions, which results in improved fuel efficiency and reduced emissions. The gasoline engine provides power during high-speed and heavy-load conditions, which further improves fuel efficiency and performance. The parallel hybrid system also utilizes regenerative braking, which converts the kinetic energy of the vehicle into electrical energy during braking. This energy is stored in the battery and can be used to power the electric motor.

One limitation of the parallel hybrid system is the complexity of the powertrain. The parallel hybrid system has more components than a traditional gasoline-powered vehicle, which results in increased maintenance and repair costs. The parallel hybrid system also has limited electric-only range, as the electric motor is not the primary source of power and is only used during low-speed and light-load conditions [3].

2. Proposition of hybrid system for ultralight aircrafts

Block diagram of presented solution is show on Fig. 1.

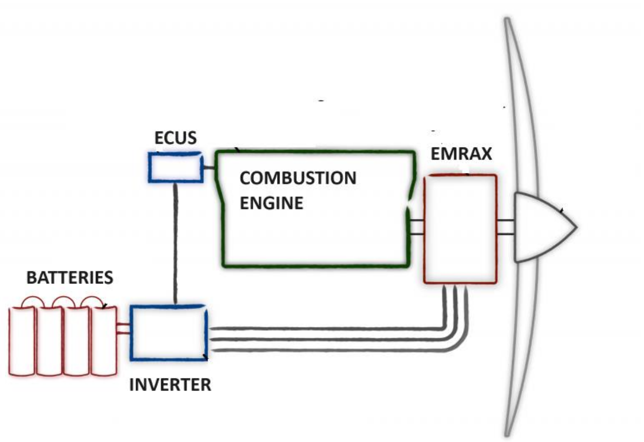

Fig. 1. Block diagram of proposed hybrid system

The diagram (Fig. 1) shows the basic components of a serial hybrid aircraft engine.

The combustion engine is connected together with the electric motor through a shaft and further drives the propeller. The electric motor is also a generator that allows both to supply mechanical power to the main shaft of the unit and to recharge the batteries during the flight [1].

The main converter is a bi-directional converter that allows energy to flow to and from the batteries. The converter also determines the operating state of the internal combustion engine.

This solution requires a specific design of the electronic controller of the internal combustion engine.

Due to the generally accepted standards for aviation, the internal combustion engine controller was built as two independent units. The first unit is responsible for generation the fuel injection sequence and the second unit is responsible for generation the ignition sequence [4].

All three controllers – the main converter, the injection controller and the ignition controller are connected by a common CAN bus.

On figure 2 laboratory stand is presented.

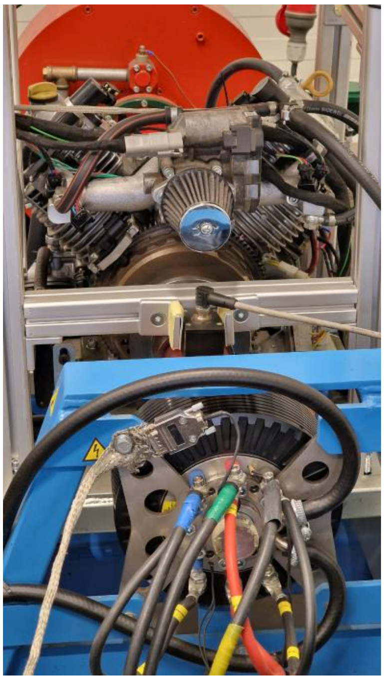

Fig. 2. Laboratory stand for hybrid system testing

2.1. Mechanical part of system

The object of the research is a two-cylinder internal combustion engine in the system V. It is a spark-ignition, air-cooled, non-supercharged four-stroke engine with a maximum power of 35 HP at a rotational speed of 4640 rpm. Engine view and some important technical informations are presented below.

Fig. 3. Vaxell VX 40I engine (Vaxell datasheet)

Table 1. VX 40I basic technical information (Vaxell datasheet)

Construction	2 cylinder V2/90°
Continuous power	35 hp at 4 640 rpm
Dry weight	34.6 kg
Cooling	air
Reduction gear unit	1:1.77
TBO	1500 h
Propeller RPM	2620 1/min

This engine is coupled with the EMRAX motor / generator by direct connection through the drive shaft. The choice of this element was caused by its low weight, high power and ease of installation.

EMRAX view and some important technical informations are presented below.

Fig. 4. EMRAX Axial flux motor / generator (EMRAX datasheet)

Table 2. EMRAX basic mechanical information (EMRAX datasheet)

Type:	Axial flux motor / generator
Casing diameter:	208 mm
Axial length:	85 mm
Dry mass:	9.4 kg (AC) / 10.0 kg (CC) / 10.3 kg (LC)
Stator cooling:	air (IP21) / combined (IP21) / liquid (IP65)
Mounting:	Front: 6x M8 threaded holes Back: 16x M8 threaded holes
Stacking:	Two motors can be stacked together to achieve doubled power / torque

Table 3. EMRAX basic electrical information

Maximal battery voltage:	580 (HV) / 390 (MV) / 140 Vdc (LV)
Peak power(at 6000 RPM):	86 kW
Continuous power*:	up to 56 kW
Peak torque:	150 Nm
Continuous torque*:	up to 90 Nm
Efficiency:	92-98%

*Subject to drive cycle, thermal conditions and controller capability.

2.2. Injection electronic control unit

The electronic unit controlling the operation of the internal combustion engine is designed to generate the appropriate impulses to stimulate the injectors on the basis of strictly specific input signals. The inputs for such a signal are:

1. RPM – hall effect engine speed sensor, informing at the same time about the location of the first cylinder TDC,
2. TPS – potentiometric throttle position sensor, indicating the "intent" of the pilot,
3. MAP – air pressure sensor in the intake pipes,
4. MAT – air temperature sensor in the intake pipes,
5. FPT – fuel temperature and pressure sensor, in the fuel manifold.

Based on signals from the above sensors the dose of fuel applicable in the next one is determined.

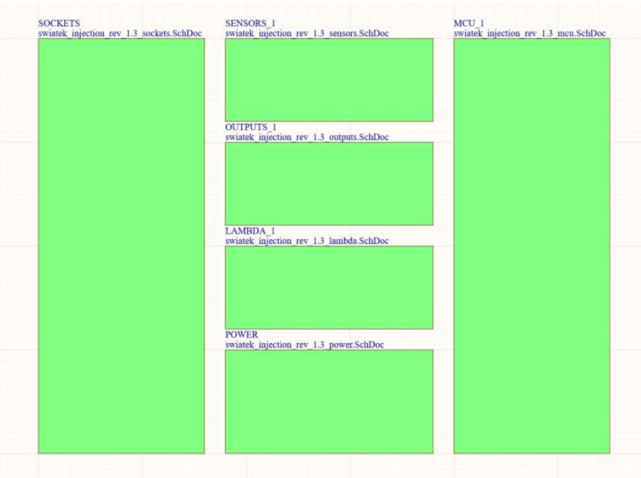

Fig. 5. Block diagram of Injection ECU

The experimental injection control unit is based on the Texas Instruments RM48L540DPGETR DSP processor. The injection sequence is built on the basis of input signals from the sensors. The injectors are controlled by current keys made in MOSFET technology. The injection control algorithm takes into account both the static states of engine operation - needed to determine the characteristic ones operating points and testing the possibility of replacing the generated mechanical power with electric power generated by the electric part of the hybrid unit.

Block diagram of Injection Controller is presented on Fig. 5.

The injection controller PCB is shown on Fig. 6.

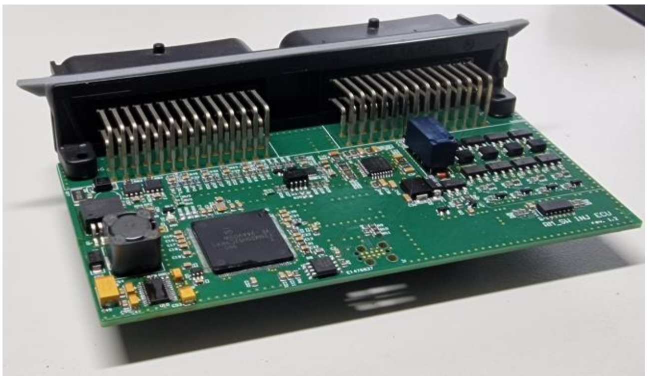

Fig. 6. Injection ECU – PCB view

Exemplary measurements of the generated sequence are presented below (Fig. 7). The yellow line shows the pulses coming from the RPM sensor. The orange line and the red line represent injector control for cylinder one and cylinder two, respectively.

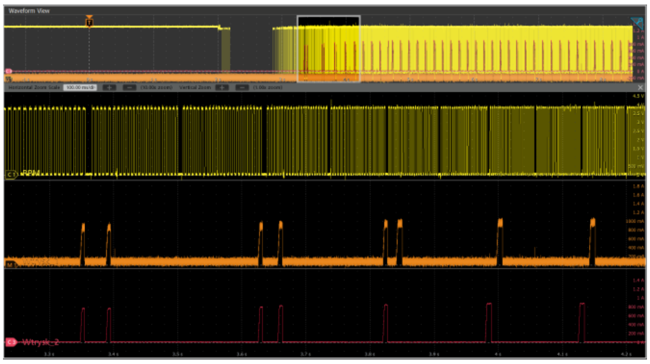

Fig. 7. Example of injection pulses sequence

The first two pulses after the rotational speed occur are caused by fuel injection and engine start-up facilitation. Later in the waveform after the start-up, an out-of-phase sequence is observed for both cylinders.

2.3. Ignition electronic control unit

The MAP and TPS sensors were used as input signals in the ignition system. In addition, a correction for the supply voltage was introduced because the supply voltage intensively affects the amount of energy stored in the ignition coil. As in the previous injection system, the same processor was used with the same necessary environment for its operation.

Block diagram of Ignition Controller is presented on Fig. 8. Main difference is between both controllers is placed in actuators section. Injectors and spark coils needs specific electronic circuits for current control.

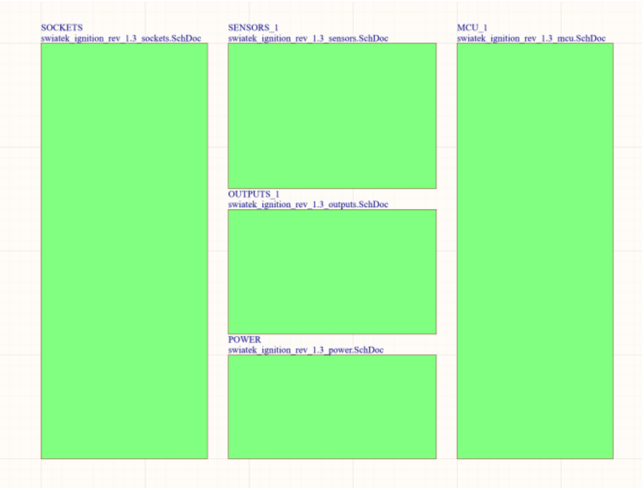

Fig. 8. Block diagram of Ignition ECU

The ignition controller PCB is shown on Fig. 9.

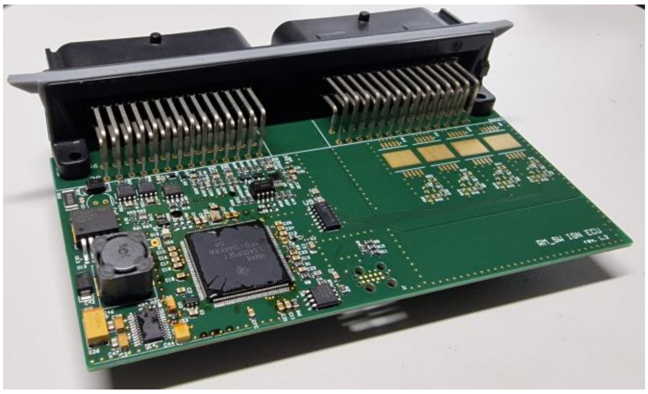

Fig. 9. Injection ECU – PCB view

The ignition coil control sequences are shown on Fig. 10.

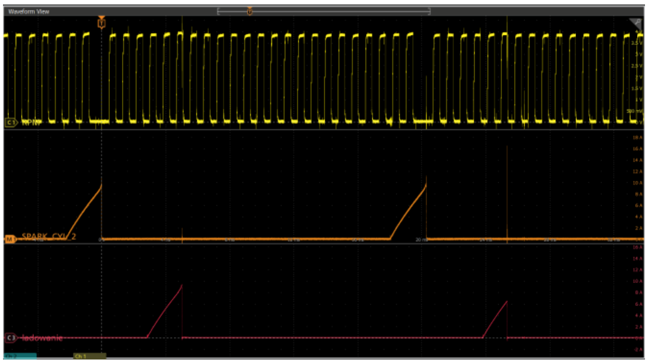

Fig. 10. Example of ignition pulses sequence

The waveform from the rpm sensor is marked with a yellow line. The orange and red lines show the ramming of the ignition coils.

The angular displacement between both cylinders of the controlled internal combustion engine is clearly visible. The duration of the control pulse depends on the supply voltage and the falling edge causes a physical spark in the engine cylinder.

3. Conclusions

The publication presents a hybrid concept and a unit that in the future may be used as a drive for an ultralight aircraft.

The current work focuses on the control of the internal combustion engine in order to achieve the proper efficiency of the process of converting chemical energy into mechanical energy.

Both injection and ignition control systems based on the input signals of the measured engine have been presented.

The optimal control process of the internal combustion engine was achieved through many hours of testing on the engine dynamometer.

The engine was loaded both with the electrodynamical brake and the EMRAX motor / generator, which in the next step in the next works will constitute the hybrid part of the proposed drive.

The most important conclusion from the work carried out is that it is possible to construct a hybrid system, it is possible to build algorithms for controlling the internal combustion engine and prepare a stand for pre-implementation tests.

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