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FUEL CONTROL SYSTEM DESIGN FOR A SMALL TURBOSHAFT ENGNIE

RATKOVSKÁ Katarína , GÁŠPÁR Roman

The content of this article is a proposal of the fuel - control system for small turboshaft engine TS - 20, which is converted into energy unit in the laboratory of Department of Power System Engineering (KKE). The original fuel – control system are not available so it is necessary to propose the new one. The new engine-control proposal for a TS - 20 calculate with a gaseous fuel usage, so the original mechanical control system of automatic regulation FADEC must be replaced as well.

Keywords: power generating combustion turbine, fuel – control system, regulation, turbo-starter TS – 20, FADEC, turboshaft engine.

1. Introduction

Turboshaft engine TS – 20, located at Department of Power System Engineering (KKE) of Faculty of Mechanical Engineering at the University of West Bohemia, is the original turbine starter whose free gas turbine is kinematically connected to the jet engine's rotor which is started. This type of turbo-starter was used for starting the engine AL-7F-1, fighter-bomber Su-7BM. A disadvantage of these motors is their short run (50 – 60 sec). For long time use in laboratory conditions is necessary to reduce power of the unit.

Original components of the fuel-control system are not available; therefore the proposal of suitable assemblies components for the system is needed. The original control system of the TS - 20 was mechanical. With respect to the contemporary situation, it is appropriate to use engine control system FADEC. FADEC system makes the selection of appropriate components in the system, especially in consideration of the proposed fuel which will gaseous**.**

2. Analysis of fuel-regulatory system for small turboshaft engine TS-20

The original TS – 20 engine had been controlled by the mechanical engine control system . Oil - Fuel Pump 414AF - 3 is assigned to supply oil and fuel to the engine during its operation. The pump has several regulatory elements.

Compressor revolutions were controlled based of measurements of the gas temperature behind gas turbine T_{4c} and afterwards are re-regulated by supplement of gas to the engine. The free-turbine was burdened until the main engine was worked properly.

Control valve of initial pressure in the fuel pump is designed to ensure the supply of fuel during engine starts depending on the pressure after the compressor p_{2c} with short term increase of the gas temperature to the maximum value given by technical conditions. The control valve consists of the bellows and adjusting screws.[8]

Fuel regulator system for engine MPM20

Experimental small jet engine MPM 20, located in the laboratory of the Aviation engineering at the Faculty of Aeronautics, is structurally modified turbine starter TS – 20. Fuel-control system of MPM 20 could be useful as an example for the proposed fuel-control system.

Parts of fuel-control system: fuel tank, fuel filter, solenoid valve, fuel pump 6223 LUN, fuel filter LUN 7165, fuel - oil unit 414AF-3, flow control valve, solenoid shut-off valve, fuel flow, fuel temperature sensor, flexible connection.

Fuel is supplied by four fuel nozzles located at combustion chamber. The fuel support is provided by fuel - oil pump 414AF - 3, which is electrically powered. The fuel is gasoline B - 70 which is drawn from a special fuel tank containing fuel in the necessary volume to trigger activity.

In the process of engine starting the fuel supply to the combustion chambers is controlled according to the pressure behind the compressor p_{2c} by the control valve of initial fuel pressure, which is located in the aggregate 414AF – 3. The initial fuel pressure value change alongside with the nature of the accretion pressure during the engine start is controlled by a screw of the control valve.

Control of output gas temperature T_{4c} of small jet engine is allowed by reducing valve, which is located in the aggregate 414AF - 3. Reduction valve allow fuel back flow to the gear pump unit 414AF-3

Measuring unit of MPM 20 engine

Measuring unit contains following parts:

- sensors, transducers,
- bus system (SCXI 20)
- the object itself - MPM 20,
- a central computer with the software and card for collecting and archiving data.

In the measuring unit in Fig. 1 have been used analog and digital sensors. The sensors were connected to the bus system SCXI 1000 with the transduction cards SCXI 1102 and 1303. This system was connected with a computer and by usage of LabVIEW program environment information was processed and appeared as a virtual dashboard for direct monitoring of engine parameters MPM 20.

Digital sensors:

- Rotating Vane Flowmeter Hoffmeter to measure fuel flow, which flows through the engine.
- Optical speed sensor Tesla, which is used to sense speed turbo engine.

Analog sensors:

- Differential K thermocouples measuring temperature T_{2c}, T_{3c}, T_{4c}.
- Induction pressure sensor - VEGABAR which senses pressure p_{2c} a p_{3c}.

- Potential sensor thrust.

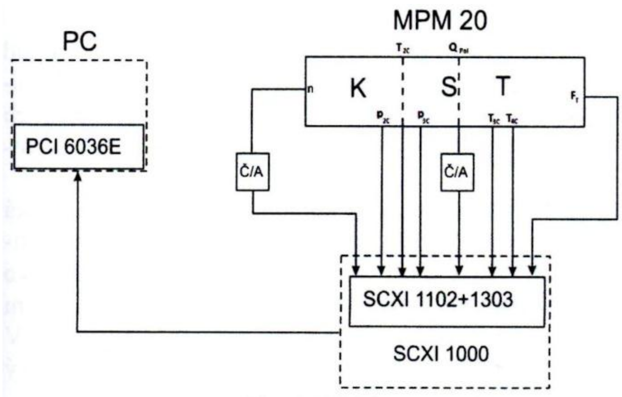

Fig. 1 Scheme of the measurement unit

3. Proposal of modifications for TS-20 fuel-control system

Since the original components of fuel – control system are not available, it is necessary to propose new components for fuel - control system. In this case, the proposal will be affected by fact that turbine starter worked at maximum power, starts the main engine revolutions to 1000 RPM during very short period (60 sec). Transformed power unit have to work longer time than 60 seconds, so the performance must be reduced.

Tuboshaft engine control

Characteristics of turboshaft engines depend on the main parameters of the engine, i. e. performance and specific fuel consumption of the engine RPM and flight conditions. As in jet engines, the flow of characteristics of turboshaft engines depends on the engine configuration and on the process of the control.

The crew controls the choice of engine work by engine control lever (POM). In the case of automatic controls, this is performed by autopilot depending on potential external disturbances. The Control program, dependence configuration n and T_{3c} position POM assign values of controlled variables to individual positions:

$$n = f(\alpha_{POM}) \tag{1}$$

$$T_{3c} = f(\alpha_{POM}) \tag{2}$$

Based on changes in position α_{POM} the control system changing control variables (fuel supply to the combustion chamber Q_{HSK} or changing a geometry of the exhaust nozzle A_5) intends to change the controlled variable (RPM and temperatures T_{3c}) under program control, which is programmed in the automatic control system, due to which leads to the change of the engine mode. After achieving the selected mode, the selected controlled variables are under automatic control and maintained. Disorders that affect the engine are removed by appropriate change of control variables. Each mode of the engine has one control program.

$$n = f(Q_{HSK}) \tag{3}$$

In case of dual spool turboshaft engine , the engine is mostlu controlled by fuel flow Q_{HSK} and the controlled variable are RPM.

$$n_{TK} = f(Q_{HSK}) \quad (4)$$

Free gas turbine connected through gearbox with the propeller, are chenged depending on the propeller blade angle of attack φ (propeller load) by the specific control law:

$$n_{VT} = f(\varphi_v) \quad (5)$$

Engine RPM are readily measured with the necessary static and dynamic stability, in contrast to the measured temperature T_{3c}. When the engine is choked, RPM decreases continuously in entire range of operating modes, it clearly defines the engine mode.

The TS – 20 is defined by tandem dual-spool construction. Engine's RPM are controlled by the flow rate of fuel and the free turbine RPM can be controlled its load, which could be a generator of electricity, which will take its mechanical performance, see equation (6).

$$n_{VT} = f(P_{el.}) \quad (6)$$

To control the fuel flow Q_p control valve LUN 6743 is suitable. For this case is necessary to find a right voltage to obtain optimal feedback for control system.

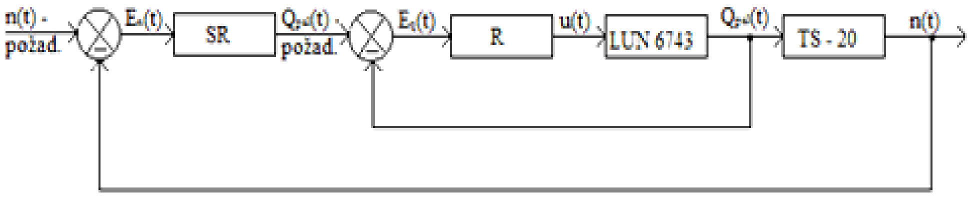

Fig. 2 Scheme of the engine control

Automatic control system

Engine control systems are designed to ensure functionality of the engine in every engine mode. The main advantage of the FADEC system is its flexibility; the digital controller is implemented in the software and modifications may be made without a complete replacement of the original controller.

The main tasks of the fuel supply to the engine:

- Manage the amount of fuel supplied to the engine combustion chamber under in entire range of engine modes.
- The system shall ensure the operation of the engine in order to maintain RPM required by pilot or aircraft controlling computer.
- The control system have to ensure that the critical values of controlled parameters will not achieve

Parts of automatic control engines working with gaseous fuel:

- Engine control block.
- Shut-off valve no.1.
- Shut-off valve no.2.
- Gas dosing valve.
- Controls block injector.
- Block motor protection.
- Blocks engines control elements that control the geometric parameters of the gas-air channel (inlet guide vane compressor, air valves, forgiveness, etc.).
- Sensors and signaling process parameters of the engines.

- Interconnecting tubing and wiring between the parts of the automatic control engines.
- Devices for vibration control engines.
- Connecting wires of the automatic control system for engine with higher levels of automatic control.
- Algorithms of management and control of engines.
- Technological counter.

The control block management may consist of a single block or be part programmatically - technical means of automatic devices pipeline compressor station.

Engine control block

Currently used electronic automatic control system operates based on microprocessors. Such devices are programmable and reprogrammable and are able to perform complex calculations. Operating display is used to display operational information and transmitting signals from the operator to the management system. The signal follows to the analog digital converter – ADC. At ADC is transformed to the digital signal.

Digital scan parameters of engines in real time, it is important to create a model and also for automatic control systems in accordance with the requirements of FADEC systems and situational management. Fig. 3 shows basic scheme of digital data collection.

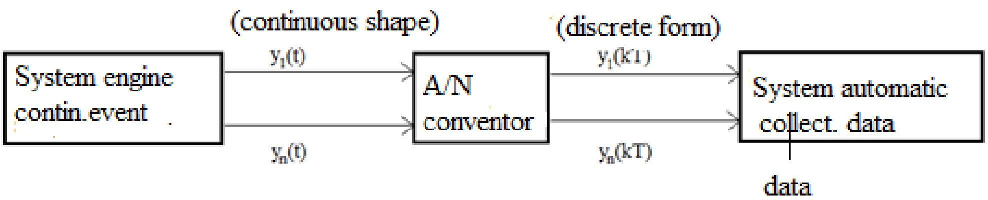

Fig. 3 Scheme of digital data collection

The information is processed by the control unit. The processing of data are according to engine controls laws. As a result created an output signal which control of the power mechanism.

Fuels for transformed aircraft engines.

Fuel is an essential source of energy that is supplied to the engine. The fuel has to deal with a few important requirements:

- High heating value and high density, which provides for engines long flight range and in the terrestrial use of its long-term operation
- Security of fuel flow
- Can be used in a wide range of ambient temperatures (from -60 ° C to +60 ° C).
- High chemical and thermal stability.
- Cannot interact with material of seals [10]
- High cooling capacity
- The use of combustion products as a working fluid in the engine
- Availability of fuel sources in nature, cost-effective campaign and processing.

- Economic efficiency and security of supply ground infrastructure, storage, loading, etc.

At present days, there are the most commonly used kerosene as fuel for engines. This fuel meets all the requirements. Transformed aircraft engines are used liquid or gaseous fuels. Nowadays, much attention is paid to the alternative fuels, especially renewable biofuels (biogas, biodiesel, alcohol, etc.), which are used in pure form or blended with conventional fuels.

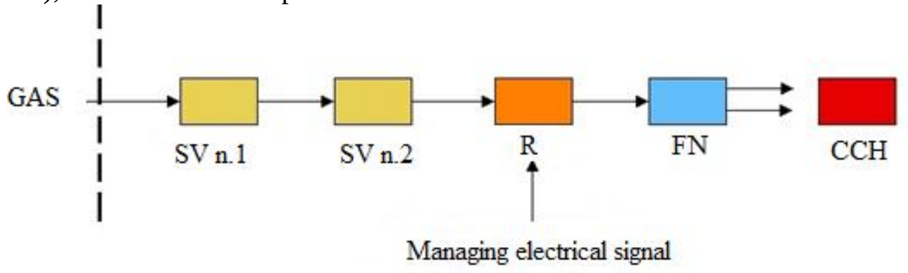

Fig. 4 Fuel system block scheme for engine using gaseous fuel

SV – shut-off valve
FN - fuel nozzle
R – control system
CCH– combustion chamber

Liquid Propan Gas

LPG is one of the alternative fuels of petroleum origin. The use of liquefied LPG for propulsion engines dates back to 1910, Europe is regarded as LPG mixture of C_3 and C_4 hydrocarbons in the United States is reputed for LPG propane. LPG is a product of oil refining or natural gas. Liquefied gas is stored at a pressure of 1.4 MPa. Thanks to the built infrastructure it is easily available.

Propane and butane are easily liquefied and stored in pressurized containers. These features make it easy to carry fuel, and therefore can be easily transported in cylinders or tanks to end-users. It is easy to strike the right balance mixture of fuel and air, allowing complete combustion. At the same time, LPG is one of the cleanest fuels in the world. It is characterized by a minimal carbon emission footprint and minimum impact on human health. It is a great alternative for the use of traditional fuels. It has very positive impact on reducing emissions from traffic transport. It does not contain a component of corrosion and thus does not degrade components and individual parts or engine design. During production, it is impuried from aggressive substances, mechanical impurities and water in the special cleaning processes. It is especially popular for its significant price saving operating costs.

Combustion of propan-butan

Propane - butane (PB) mixture in the liquid phase is a clear, colorless liquid with a specific odor and is readily volatile. It stores the compressed state in tanks and 1,5 - times heavier than air. PB diffuses slowly in areas with poor air circulation and thus an increased risk of explosion.

Reaction rate in the combustion process PB depends mainly on:

- temperatures

- pressure
- mixture concentration

Density ratio of propane and butane is 1/4, consequently:

$$\rho_t = (0{,}2 \cdot 2{,}019) + (0{,}8 \cdot 2{,}590) = 2{,}476 \text{ kg/m}^3$$

And then the calorific value of the mixture is:

$$Q_n = (0{,}2 \cdot Q_{n,p}) + (0{,}8 \cdot Q_{n,b}) = (0{,}2 \cdot 92{,}970)$$
$$+ (0{,}8 \cdot 122{,}775) = 116{,}8\ MJ/m^3$$

PB combustion process can be described by the following oxidation reaction:

$$C_3H_8 + 5\ O_2 = 3\ CO_2 + 4\ H_2O$$
$$C_4H_{10} + 6{,}5\ O_2 = 4\ CO_2 + 5\ H_2O$$

The minimum (hypothetically) part of the oxygen needed for combustion of 1 m^3 PB gaseous fuel is:

$$O_{2,\min} = 5 \cdot \frac{C_3H_8}{100} + 6{,}5 \cdot \frac{C_4H_{10}}{100} = 6{,}2$$

Therefore, the minimum amount of air for combustion is 29.5238 m3/m3.
When using LPG as fuel in aviation there are some basic requirements:

- Fuel tank for PB must be under pressure.
- All parts of the fuel system of the aircraft and engine must be adapted for use PB, fuel pump, fuel nozzles, ignition system.

4. Specific proposal of fuel – control system

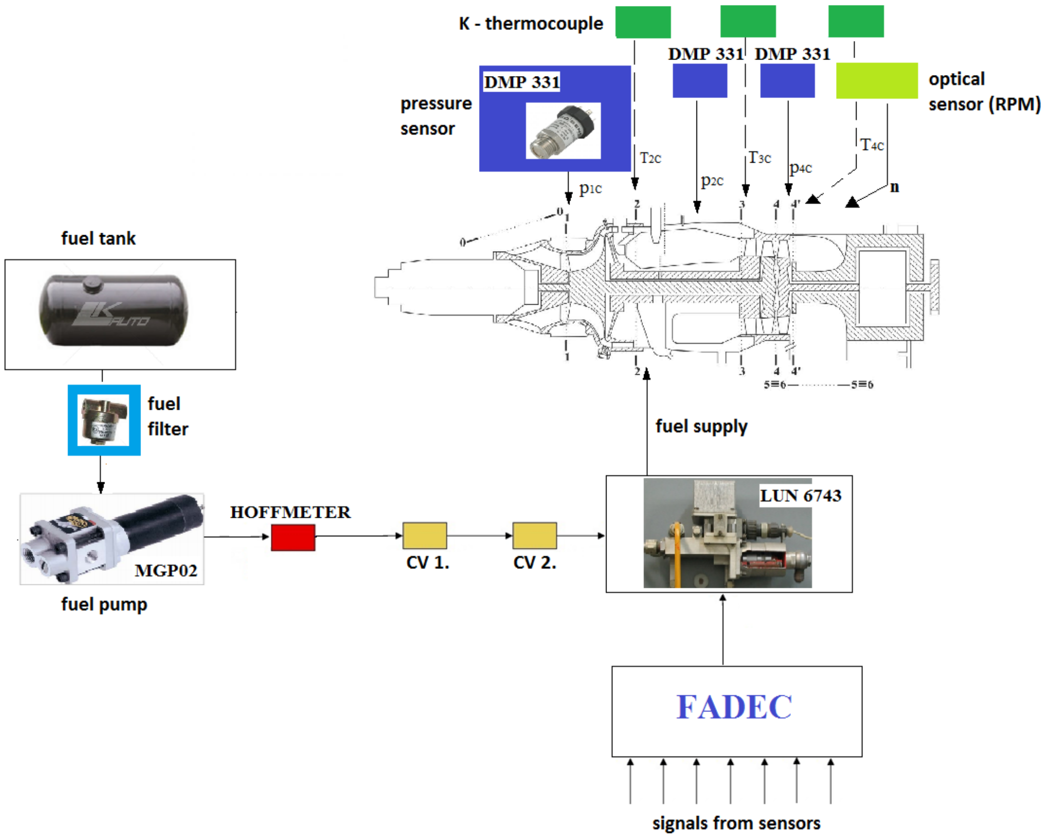

Fig. 5 Proposal of fuel – control system

Fuel tank

In the case of gaseous fuel, for example LPG, it is necessary to use by a reservoir of gas. Tank must be pressurized and hermetically closed. There can be used tanks that are used in cars, which run on LPG (Fig. 5).

Fig. 6 Fuel tank for LPG

Fuel piping

Piping (Pipes, hoses, fasteners such as hose clamps, brackets, elbows, etc.) is used to supply fuel from the fuel tank to the combustion chamber. Especially the low-pressure pipe leaks and material should be resistant to the selected fuel.

Fuel pump

The proposed pump must have following parameters:

- Minimum pressure at the outlet $p_{\_v\_min}$ = 1.72 MPa.
- The fuel pressure from 1.226 to 1.716 MPa (12.5 to 17.5 kp • cm-2).
- Fuel supply Qp = 1.37 l / min.

Pressure control is realized by throttling valve, so it is advisable to select a pump that has a pressure greater than the required minimum pressure $p_{\_v\_min}$ =1,72 MPa.

Sensors

The fuel flows through the flowmeter and pressure sensor. These sensors give information about the pressure and fuel flow. Based on these information is controlled the fuel supply.

Sensor of fuel flow - Hoffmeter

For this proposal was chose an already proven fuel flow sensor Hoffmeter, serving on the principle of a changing magnetic field, which starts spinning vane flowmeter that is in it. 1l/min fuel mass flow rate corresponds to the paddle around 50-60 Hz.[5]

Optical RPM sensor TESLA

Optical RPM sensor is a discrete sensor whose outputs are fed to the input evaluation device. It is a system SCXI 1000 with the transduction cards SCXI 1102 and 1303. This system is able to handle only analog output signals and therefore there have to be also ADCs.

The pressure sensor

The Department of Power System Engineering already purchased pressure sensor - DMP 331, which is used to measure the relative and absolute pressure of liquids, gases and vapors.
Properties DMP 331:

- Range from 10 kPa to 60 MPa.
- Accuracy 0,35 %, 0,5 % (0,25 %, 0,2 %, 0,1%).
- High overload, good linearity, accuracy and stability.
- Intrinsically safe version (Ex) II 1 G Ex ia IIC T4 Ga, (Ex) II 1 D Ex iaD 20 T 85°C.
- Type test TCM 173/94-1905.
- Certified SIL 2 dle IEC 61508 / IEC 61511.

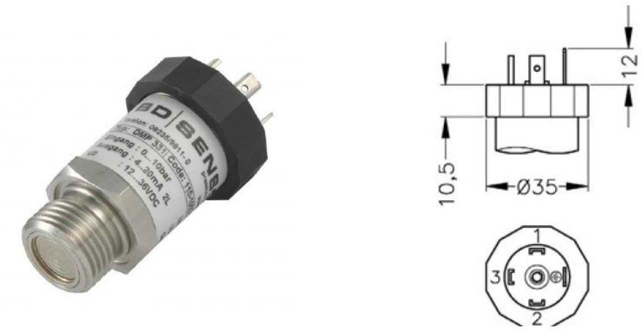

Fig. 7 DMP 331

Servo valve

Control system - to control fuel flow to the engine is utilized the servo valve (fuel distributor) LUN 6743.

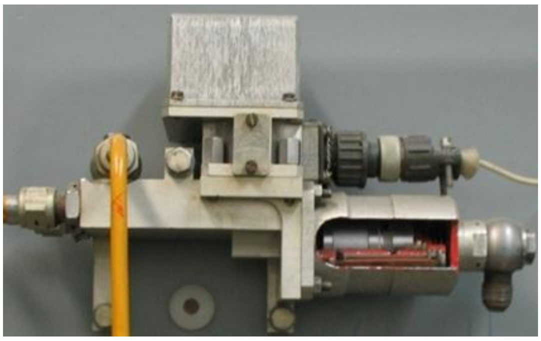

Fig. 8 LUN 6743

LUN 6743 ensure fuel supply to the engine fuel nozzles and further regulates the flow of fuel in the fuel return line from the engine circuit. It means for this case, the connection of the fuel nozzles must be different.

5. CONCLUSION

Proposal for fuel - control system for engine with gaseous fuel type allows the usage of small turboshaft engine TS - 20 in laboratory conditions of KKE as a power unit for experimental and educational purposes. The original mechanical control system was replaced in the design of digital systems management – FADEC. This decision follows a lot of new elements of the control system. Theoretical design of fuel - control system will continue its practical design and verification functionality. In accordance with experiments and further use of turboshaft engine TS - 20 as an energy unit at KKE, will be necessary further modification of fuel-control system.

References

[1] HOCKO, Marián: Malý prúdový motor MPM 20, Košice: VLA-MRŠ, 2002
[2] ŽIŽKA, Václav - Návrh úpravy turbínového spúštěče TS – 20B na laboratórny turbohriadeľový motor, Diplomová práca, Plžeň, 2012, 107s
[3] RŮŽEK, Josef: Teorie leteckych motorů, Čast II., VA AZ Brno, 1983, 417 s.
[4] GÁŠPÁR, Roman: MPM 20 ako systém s dvoma stupňami voľnosti, Diplomová práca, Košice: Technická univerzita v Košiciach, Letecká fakulta, 2011, 70s.
[5] VILINSKÝ, Martin: Digitálny systém snímania parametrov malého prúdového motora MPM – 20, Bakalárska práca, Košice: Technická univerzita v Košiciach, Fakulta elektrotechniky a informatiky, 2009, 55s.
[6] PEČÍNKA, Jiří: ZKUŠEBNÍ STANOVIŠTĚ JPM-TS-20, Diplomová práca, Brno, Vojenská akademie Brno, Fakulta letectva a PVO, 2003, 74s.
[7] HUČKO, Ondrej: Experimentalna identifikacia servoventilu LUN 6743, Bakalárska práca, Košice: TUKE-FEI, 2009, 56s.
[8] LAZAR, Tobiáš, MADARÁSZ, Ladislav: Inovatívne výstupy z transonického experimentálneho pracoviska s malým prúdovým motorom, Košice, Vydavateľstvo elfa, s.r.o., 2011, 348s. ISBN 978-80-8086-170-4
[9] HOCKO, Marián: Transformace leteckých lopatkových motorů na spalovací turbíny, ISBN 978-80-261-0218-2, ZČU Plzeň 2012
[10] OLŠOVSKÝ M. , HOCKO, M.: The effect of biofuel addition to flight kerosene on a rubber gasket - 2011. In: Transport. Vol. 26, no. 1 (2011), p. 106 - 110. - ISSN 1648-3480
[11] HOCKO, M., LUKÁČ, L., PÁSTOR, M.: The propane-butane combustion in jet. In: Acta Avionica. Roč. 10, č. 16 (2008), s. 44-48. - ISSN 1335-9479

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Ing. RATKOVSKÁ Katarána, Letecká fakulta Technickej univerzity v Košiciach, Katedra leteckého inžinierstva, Rampová 7, 041 21 Košice
Ing. GÁŠPÁR Roman, Fakulta strojní, Západočeské univerzity v Plzni, Katedra energetických strojů a zařízení, Univerzitní 8, 306 14, Plzeň