THE HYBRID PROPULSION SYSTEMS FOR THE ADVANCED AIRCRAFT

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Abstract

The aim of the research is development of propulsion systems (PS) and auxiliary power unit (PU) concepts based on hybrid gas turbine engines (HGTE). Additional power (besides energy produced gas turbine of the engine) needed for the shaft rotation of the fan: fan (in a turbofan engine) or propeller (in a turboprop or turboshaft engines) supplies from an electric motor (EM) fed from external electrical sources in HGTE. They may be the storage battery, board power unit including electrochemical generator (ECG) on the various types of fuel cells (FC)

The obtained HGTE performances will be used for following comparative evaluation on efficiency indicators of advanced airliners. The main problems and critical technologies in provide for establishment of a hybrid PU are identified.

1 Introduction

Great promises to future improvement of aircraft fuel efficiency as well as environmental and operational performances are linked with the application of FC composed of PS and PU, directly converting of fuel chemical energy in electric power without combustion The progress achieved recently on FC development allow to considering them as main and supplement energy sources on the aircraft board. For example, PU using on the basis of FC allow obtaining following potential advantages:

- increasing the efficiency of used energy on the aircraft board (efficiency up to 50...60%);
- ground operations performing (preflight training for the flight and taxiing) without CO_2 and NO_X emissions as well as reducing emissions into the atmosphere from PS during the flight;
- additional advantages by the use of by-products of FC work (inert gas, water);
- reduction of noise from the PU work and other.

Applied to the HGTE can be noted that it have significant advantages compared to the traditional scheme of engines in specific fuel consumption. At the same time, the acute problem to provide acceptable level of mass-dimension performance of HGTE for aviation application, first of all, due to the high specific mass FC and PU currently exist. Improvement of their specific indicators for effective use on aircraft board (on order and more) is required.

The results of estimations based on forecast of aviation technical systems and design solutions of the domestic (TsAGI and CIAM institutes of the Russian Academy of Sciences [1, 2]) and foreign (NASA [3, 4], Boeing and others) specialists.

2 Target setting

There were considered the most rational variants of ECG application: in the near-term outlook as the PS for lightweight un-manned aerial vehicles (UAV), in the medium term as board PU and in more distant outlook as in hybrid PS of passenger and cargo aircraft.

The possible shapes of hybrid PU based on FC of different types: polymer low-temperature electrolyte membranes FC (PEM FC) and high-temperature solid oxide FC (SOFC) are conceptually necessary formed.

2.1 Investigated schemes of hybrid PS

PS based on following schemes of HGTE are investigated in this work:

- HGTE-1 scheme with additional power supply to the fan shaft from EM (see Fig. 1). EM 7 powered from an external electrical source 8 is installed on the fan shaft of traditional turbofan engines in this scheme. You can reduce fuel feeding in the combustion chamber (CC) 4, and the necessary level of HGTE thrust provides by supplying the missing power to the fan 1 from EM 7
- HGTE-2 scheme with use ECG based on SOFC battery is paralleled or instead of the traditional CH (see Fig. 2).

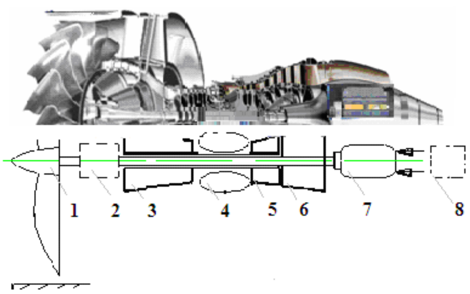

Fig. 1. The HGTE-1 scheme:

1 - fan, 2 - gearbox, 3 - compressor, 4 - combustion chamber, 5 – turbine of compressor, 6 - fan turbine, 7 - electric motor, 8 – external PU

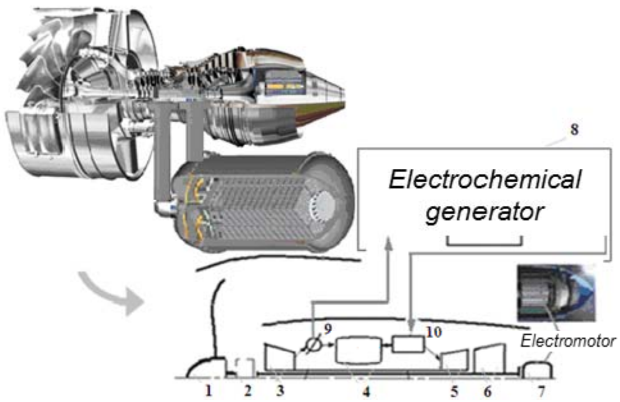

Fig. 2. The HGTE-2 scheme:

1 - fan, 2 - gearbox, 3 - compressor, 4 - combustion chamber (CC), 5 – turbine of compressor, 6 - fan turbine, 7 - electric motor, 8 – ECG based on SOFC, 9 - valve of regulating of air distribution between the ECG and CC, 10 – mixer of gases from the ECG and CC

The principal difference between their schemes is that for HGTE-1 electric energy generation carried out without the participation of gas turbine parts of the engine. In the scheme HGTE-2 electric energy is generated due to the part of air after compressor take-off of engine and it feeding in the ECG, and hot gas-out from the ECG mixes with the gas-out from the CC, and depending on the turbine.

Common for HGTE-1 and HGTE-2 schemes is that the produced electric energy supplies to the engine as additional to the power of the low-pressure turbine by the use of EM, installed on the low-pressure rotor shaft.

2.2 Investigated schemes of hybrid PU

PU based on FC, in fact, is a hybrid PU consisting of two main parts: turbocompressor block (TCB) and ECG. TCB includes a turbocompressor, electric generator and exchanger-recuperator. ECG consists of a FC battery (PEM or SOFC) and working body conditioning system for FC.

Because up to date it is not clear on what type FC should bet when creating the first demonstrator and subsequently onboard aircraft PU, it is necessary parallel research of PU different types and schemes.

Consider all four variants of schematic solutions of PU with FC: variant №1 – ECG based on SOFC; variant №2 – ECG based on PEM with traditional method of hydrogen producing from kerosene (method of autothermal reforming); variant №3 – ECG based on PEM using kerosene conversion reactor into hydrogen; variant №4 – ECG using of kerosene dehydrogenation and membrane separator for pure hydrogen production.

The simplest scheme has a variant №1 (Fig. 3), since it uses the easiest way to obtain working body from kerosene (H_2 and CO) for FC. PU variants based on PEM (№2, 3 and 4) have a more complex structure, due primarily the fact that working body for PEM is only hydrogen.

In this connection, there has been made a choice of external energy source for EM drive in favor of SOFC power unit (variant №1) for hybrid engine scheme in this work. Moreover,

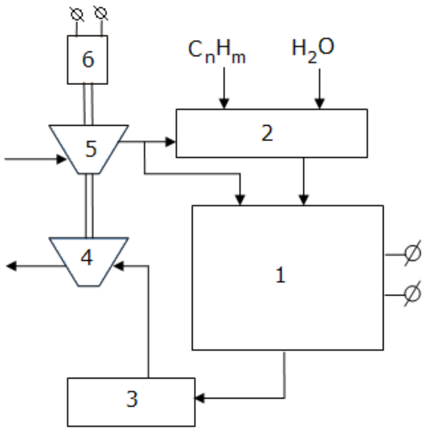

Fig. 3. The scheme of the PU based on SOFC and kerosene autothermal reforming

1 - fuel battery; 2 - reformer; 3 – reburning chamber; 4 - gas turbine; 5 - air compressor; 6 - electric generator

PU based on SOFC will have more efficiency depending on the used fuel type [5].

3 Analysis of received results

The optimal parameters of working process of both HGTE schemes have been defined in this performed work. At calculation of HGTE performance it was assumed that PS and PU for their work should only use staffing fuel, on-board itself aircraft (in this case aviation kerosene was considered).

«Basis» for the gas turbine construction of HGTE with take-off thrust $T_{T/O}$≈8 tf was the double-shaft turbofan without booster. Additional electric power (N_e) value of which was set as a fraction of about total required capacity of low pressure turbine (LPT) at cruising mode (at the altitude equal to H=11 km and the Mach number equal to M=0.78): $\delta N_e = N_e/(N_e+N_{LPT})$. Absolute value of this capacity is constant on other modes (N_e=const).

The calculation study of influence of working process parameters (turbine entry temperature TET, overall pressure ratio OPR, bypass ratio BPR) at cruising specific fuel consumption CR_{cr} and mass and dimensions parameters of HGTE were carried out for the accepted level of perfection HGTE components (fan efficiency η_{FAN}=0.93, compressor pressure ratio (CPR) efficiency η_{CPR}=0.86, high pressure turbine (turbine of compressor) efficiency η_{HPT}=0.905, low pressure turbine (fan turbine) efficiency η_{LPT}=0.93) and parameters HGTE constraints (Table. 1).

Table 1. The parameters HGTE constraints with take-off thrust of 8 tf

CPR ≤ 20
Fan diameter D_{FAN} < 2 m
BPR ≤ 20
TET_{max} = 1900 K
Temperature in SOFC T_{SOFC} ≤ 1050 ℃

It is established, that at a constant values of cruising thrust T_{cr}, CPR, TET, selected constraints (see Table 1) and increasing value up to δN_e=40% we can implement engines with lower value of fan pressure ratio (FPR) and, respectively, higher BPR. A further increase of the electric power supply does not possible to reduce specific fuel consumption, because we already achieved the limit value FPR.

On this basis, methodology which includes determining the design parameters range on the cruising regime, preliminary identification of rational HGTE parameters, the health research of the engine on other regimes, including on the take-off regime had been proposed for rational HGTE parameters. Example of thus defined by range design parameters for HGTE-1 scheme presented on Fig. 4.

From the obtained areas of design parameters in the coordinates TET–FPR–CPR–BPR selected the best variants of HGTE provided minimum values CR.cr. For its values we calculated altitude speed, throttle and mass-dimension performances, which were the source data for estimation of HGTE by indicators of aircraft efficiency. Detailed results of this

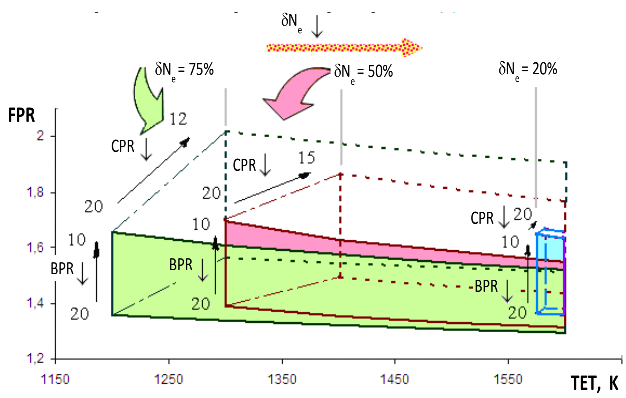

Fig. 4. Cruise design parameter ranges of HGTE-1 for kerosene (R=1200 kgf, H=11 km, M=0,78)

estimation applied to short-medium hall aircraft (SMHA) with its weight and aerodynamic level, predicted on 2025-2030 years are presented in [6].

Note that the choice of varying scheme of hybrid PS or PU in combination with used fuel will be to determinate requirements into developed aircraft of a specific purpose, and also reached level of technological readiness appropriate technologies.

4 Demonstrator of PU with ECG

«CIAM 80» and «CIAM 80-2» with PU on the basis of PEM running on gaseous hydrogen made in CIAM named after P.I. Baranov first time in Russia.

«CIAM 80» UAV (Fig. 5) having electric engine to drive the pulling the propeller in flight fed only on PEM battery and BLAH «CIAM 80-2» UAV with more large sizes than «CIAM 80» has electric engine feeding in the flight from the battery. PU based on PEM used for power supply of communication equipment, control systems and steering machines to reject the controls of aircraft.

In both cases, Aeropak PEM FC battery production «Horizon» company of Singapore, which produces electric power up to 250 W (Fig. 6) is used. The Aeropak FC battery by its performances is one of the best in its class.

At present, the PEM FC domestic battery capacity 750W installed on the new «CIAM-Record» flying laboratory is developed and soon it will be demonstrated into the flight.

Fig. 5. The first flight of «CIAM 80» UAV

Fig. 6. Onboard PU «CIAM 80-2» UAV

1 - Aeropak PEM FC battery, 2 - fuel tank, 3 - gas pressure regulator, 4 - control system

5 Critical problem of hybrid PS and PU development

The solution of main issues which associated with in the near term providing the possibility of creating high-efficiency hybrid PS and PU based on FC for different purposes aircraft:

- absence of FC with high specific performances;
- requires the development of effective devices of synthesis-gas obtaining with hydrogen production and/or effective way to store hydrogen onboard aircraft;
- necessary to create EM with high specific performances.

We must create demonstration bench of PU with low power in order to develop of critical technologies to provide development of full-size hybrid PS and PU.

6 Conclusion

1. The concepts of hybrid PS and PU for advanced aircraft are investigated and developed.
2. Rational ranges of design parameters are defined. Optimal variants of HGTE two schemes are selected by calculation for further efficiency estimation on the aircraft.
3. Possible schemes of hybrid PU based on PEM FC and SOFC are investigated. Basic advantages and disadvantages are identified.
4. The list of critical technologies for hybrid PS and PU development is defined.

5. Operability of PS and PU based on FC is successfully demonstrated on number small-sized flying laboratories of CIAM.

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