AN ELECTRICAL FUEL PUMPING AND METERING SYSTEM FOR MORE ELECTRICAL AERO-ENGINES

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Abstract

In the frame of the POA (Power Optimised Aircraft) programme in the 5th PCRD, HISPANO-SUIZA has designed, manufactured and tested an advanced fuel system called EFPMS or Electrical Fuel Pumping and Metering System.

On one hand, in a more electrical aircraft, engine will also be "power optimised". In a mid to long-term, the accessory gearbox could actually be removed and the conventional secondary systems driven by this mechanical system would then be electrically driven. On the other hand, the possibility to have the speed of the pump (and the fuel flow) completely independent of the engine rotor speed has a lot of interest, as there is no more use of the conventional metering unit in the fuel system.

Among other advanced electrical equipment systems for More Electrical Aircraft, the EFPMS is a step towards an optimised and simplified fuel system. The speed regulation of this pump driven by an electrical motor allows a very precise metering of the fuel quantity at all time. The use of a mass flowmeter already leads to a great precision and the continuous improvement in power electronics packaging and electric machine control technology will lead to a greater interest for this innovative and versatile fuel system.

1 General Introduction

Started in 2002 in the frame of the 5th PCRD, the Power Optimised Aircraft (POA) [1] programme looked at possible means of reducing non-propulsive energy consumption on-board the aircraft. HISPANO-SUIZA has been involved as a Project Coordination Committee member as well as the integrator of the Aircraft Systems Validation Rig (ASVR), designed to characterise the High Voltage Direct Current (HVDC) power network of a More Electrical Aircraft.

In the frame of the Engine Systems Work Package of the project, HISPANO-SUIZA designed, manufactured and tested an advanced fuel system called Electrical Fuel Pumping and Metering System (EFPMS).

1.1 The Fuel System in Aero-Engines

Today, the fuel system of an aircraft engine is constituted of a mechanically driven pump, attached to one gear of the accessory gearbox. The main flow delivered by the pump is directly linked with the speed of the dedicated gear, itself proportional with the speed of the engine shaft. By the use of valves, the excess of fuel is returned in the circuit or in the fuel tank. Also a hydro-mechanical fuel metering unit is used to distribute only the requested amount of fuel to the injection ramps of the engine.

A lot of energy is used to unnecessarily circulate all this fuel in the circuit. This energy also turns into heat, making the fuel hotter.

1.2 More Electrical Engine Systems

In a more electrical aircraft, the power plant will be "power optimised" id est the non-propulsive energy will be rationalised. In a mid to long-term, the accessory gearbox could actually be removed. All the conventional secondary systems, up to now driven by this mechanical power transmission, would then have to be electrically driven.

The challenge in a more electrical engine is to properly integrate the power generation system and distribute this electrical power adequately around the engine and to the aircraft. Engine equipment systems then use this electrical power.

The main hydraulic pumps could be replaced by local hydraulic circuits or by a more generalised use of electro-hydraulic or electro-mechanical actuators.

Towards an oil-less engine, the insertion of Active Magnetic Bearings (AMB) would become enabled by the electrical power available in the engine area.

Variable geometries in the engine area, from variable bleed valving to variable stator blade actuation, would also benefit from electrification, allowing a tighter control of the engine.

In the nacelle, the Thrust-Reverser Actuation System is already becoming an electro-mechanical actuator, presenting advantages in comparison to conventional solutions. A simplified maintenance is made possible by the absence of fluid, suppressing the need of hydraulic services to the engine. All electric nacelles will no longer require hydraulic or pneumatic sources on engines, removing complexity and weight.

The Fuel and Oil Systems are greatly impacted when moving towards a more electrical engine. Some technical challenges have to be faced, from a technology and an architecture point of view. Nevertheless, electrification of these two functions, especially the fuel system, appears to present several advantages.

1.3 More Electrical Fuel and Oil Systems

On a more electrical engine, oil pumping and oil breathing functions would also become more electrical, using pumps and rotating foam filters driven by electric motors, but also more advanced techniques such as electro-static air and oil separation.

In the case of the fuel system, the pump would be mechanically attached to an electrical motor. The laws to control the pump would have to be carefully looked at, as well as the overall control loop, to be integrated on a more electrical engine.

When an electrical motor drives a pump, the possibility to have the speed of the pump (and so the fuel or the oil flow) completely independent of the engine rotor speed has a lot of interest. Same thing for the oil breather, where the “breathing” efficiency can be maximum, even at idle speed, where a conventional air-oil separation device reaches its limits.

For the fuel system, as it is possible to drive the pump to the exact speed necessary to obtain the requested fuel flow and so provide the engine with the exact amount of fuel to be burnt, there is no more need for a conventional hydro-mechanical metering unit in the fuel system.

2 Technical description of the fuel system in its POA configuration

2.1 POA Fuel System overview

In its POA configuration, the EFPMS is an autonomous system, which is made of a pump linked with a 75 kW electric motor. An electric converter built by Thales AES powers this motor. Both the motor and the converter are made of three independent subsystems for a greater redundancy. The system is designed so that two sub-machines are enough to drive the pump for max fuel flow (take-off). The controller exchanges data with the FADEC (Full Authority Digital Engine Controller) through a redundant digital bus (CAN) at all time, monitoring the system and ensuring the fuel regulation.

2.2 Components Description of the EFPMS

2.2.1 Pump

The pump is composed of two stages, High Pressure and Low Pressure. It is very close to a purely mechanical version, usually driven by one of the gear of the engine accessory gearbox.

2.2.2 Motor and converter

This part is a shared work between Thales AES and HISPANO-SUIZA. The converter and the active parts of the motor are designed and manufactured by Thales AES. The motor is designed and assembled by HISPANO-SUIZA. The motor is a 75 kW permanent magnet synchronous machine. The converter used to power this motor in the POA configuration is in fact a copy of the POA High Pressure Starter-Generator converter, a 210 kW unit using IGBTs.

Based on the need to have a very high level of system's reliability and availability, a solution based on redundancy was proposed by the design team. The motor drive is in fact made of three sub-drives. Both the motor and the converter are made of three independent subsystems for a greater redundancy. The system is designed so that two sub-converters powering two sub-machines are enough to drive the pump up to the maximum requested fuel flow corresponding to aircraft take-off.

2.2.3 Controller

The controller exchanges data with the FADEC (Full Authority Digital Engine Controller) through a redundant digital bus (CAN) at all time, monitoring the system and ensuring the fuel regulation. In order to make the fuel system prototype as autonomous and independent as possible it was decided to have a dedicated controller associated with this function.

Based on a small engine electronic control unit, it has about as many inputs and outputs as a small FADEC.

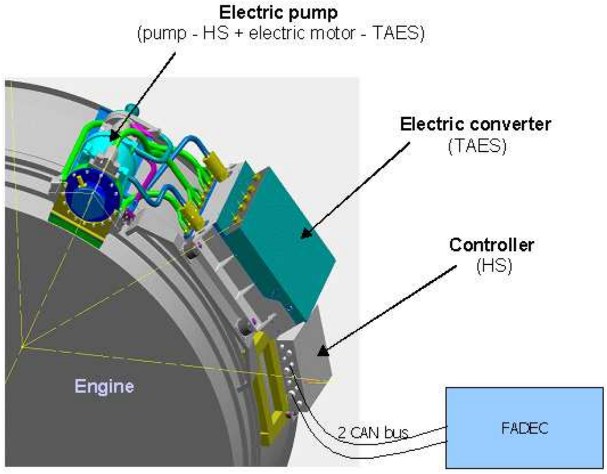

Fig.1. The EFPMS components

2.4 The Engine Systems Validation Rig

In the integration and optimisation work package of POA, a platform called Engine Systems Validation Rig (ESVR) has been conceived and operated by Rolls-Royce. The objective is to demonstrate that electrical power generation and accessory sub-systems can be fully integrated with traditional turbo-machinery and to explore the possibilities to remove the gearbox and oil system from future engines.

This more electrical engine runs with embedded generators and more electrical accessories. Main components of this platform include:

- Embedded High Pressure Starter Generator (HPSG)
- Embedded Low Pressure Fan Shaft Driven Generator (FSDG)
- Electrical Oil System
- Electrical Fuel Pumping and Metering System
- Active Magnetic Bearings
- Electrically actuated variable geometries
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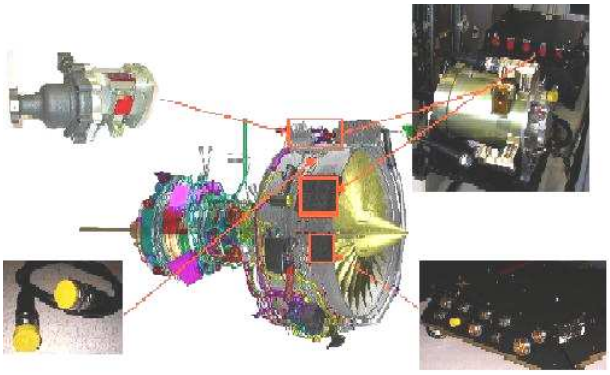

Fig.2. Installation of EFPMS on the ESVR

2.5 The fuel as a cooling media

On the Engine Systems Validation Rig, oil and fuel are also used to transfer calories from hot sources to cold sources. Indeed, the fuel is for instance used to cool down the motor pump itself and its associated converter.

The fuel is also used to cool down the power electronics converters of the two generators. These converters are installed on the fan case and their cold plate is linked with the fuel system. This solution has been chosen in the frame of this project but it is not the only solution for managing heat around the engine. The oil system is also used as a cooling media, circulating in the two machines of the power generation system.

This requirement for cooling capability has been a design driver for the EFPMS system. Compared to a conventional system, the pump must for instance start its rotation before the engine rotates in order to ensure that no hot spots will appear in the electronics prior to engine running.

2.6 EFPMS Functional Description

2.6.1 EFPMS functions

The EFPMS functions are defined hereafter:

- to provide appropriate fuel flow rate to the HMU corresponding to the absolute fuel flow rate demand sent by the Master Engine Controller (MEC),
- to provide the fuel flow requested for the cooling of the electrical generators (HPSG and FSDG) power electronics,
- to ensure its own cooling,
- to limit the pressure in the fuel system,
- to drain its leakages,
- to provide stable closed loop control of the electric fuel pump throughout the engine running range, in response to a fuel flow demand,
- to supervise its state of health and reconfigure the system when failures occur,
- to communicate with the MEC through the Engine Data Bus.

The EFPMS also includes a test data logging facility plug.

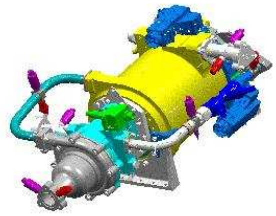

Fig.3. The motor assembled with the pump

2.6.2 Operating process

The fuel delivered to the EFPMS inlet is set under pressure by the EFPMS LP pump.

Then, the fuel transits in the electrical motor and power electronics cooling system in order to dissipate the thermal rejection of these two components.

Moreover, it cools the engine FSDG and HPSG power electronics and also circulates in the pressure relief valve settled in parallel.

3 EFPMS Validation and Integration

Prior to assembly, the components of the systems were individually tested. Converter and machine were tested and validated on partial test benches. The controller was tested and tuned on a Hardware In the Loop platform.

Once completed, the EFPMS has been validated on four different platforms:

- A fuel test bench platform
- A simulation platform

- The Engine Systems Validation Rig
- The Aircraft Systems Validation Rig

3.1 Fuel Test Bench Campaign

Once manufactured the Electrical Fuel Pumping and Metering System was tested internally on a fuel test bench in Réau, south of Paris. Tests results showed the capability and performance of the system and the initial digital models were updated and tuned according to these results. The objectives of these tests were also to prepare integration on the POA simulation tool and test platforms.

Fig.4. The EFPMS tested on a fuel test bench

The EFPMS was tested in terms of dynamic performances. For instance the outlet pressure corresponding to the fuel flow demand was shown to be reached after less than 0,5 second.

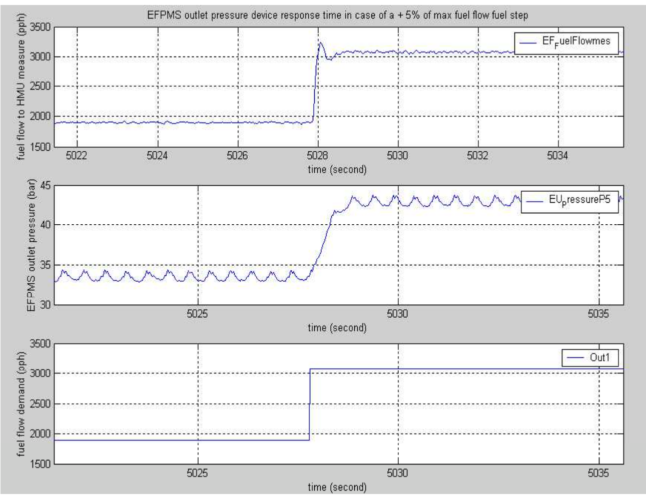

Fig.5. Step response for outlet pressure

3.2 POA Simulation Tool Campaign

The updated numerical model has been integrated into the VIB (Virtual Iron Bird), a powerful simulation and optimisation tool developed in the frame of the POA project. The EFPMS model was compared to a model of a conventional fuel system and used in the More Electrical Architectures in the rationalisation and optimisation process of engine and aircraft power systems.

3.3 Engine Systems Validation Campaign

One of the EFPMS systems has been delivered to the partner Rolls-Royce responsible for its integration on a demonstration aero-engine the ESVR (Engine Systems Validation Rig). The objective is to demonstrate the capability of the pump to run on a conventional turbo-machinery, even if the mechanical gearbox is removed. It was also shown that the conventional metering unit could potentially be removed in the future.

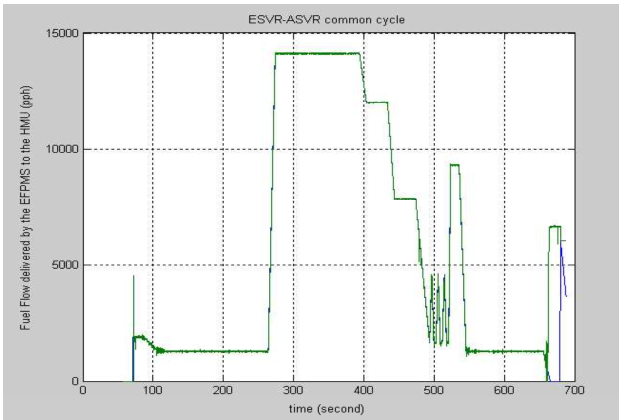

Fig.6. EFPMS response to short service readiness cycle

3.4 Aircraft Systems Validation Campaign

In parallel of the other test campaigns, one of the EFPMS demonstrators was connected to the ASVR (Aircraft Systems Validation Rig) aircraft electrical network. Through a dedicated control interface, the distributed fuel system architecture was represented, including the FADEC (Full Authority Digital Engine Controller) and a dedicated measurement system to evaluate the power consumption in the aircraft electrical environment.

4 Achieving objectives towards an advanced aircraft fuel system

An advanced electrical equipment system for More Electrical Aircraft, the EFPMS (Electrical Fuel Pumping and Metering System) has been demonstrated in the POA project. This step towards an optimised and simplified fuel system is paving the way towards the More and All Electrical Engine.

A high level of precision is reached in the metering of the fuel quantity at all time without any need of additional hydromechanical metering system. In order to achieve this tight regulation, a mass flowmeter associated with the relevant electronics is used.

The continuous improvement in power electronics packaging, sensors and electric machine control technology will lead to an even greater interest for this innovative and versatile fuel system.

References

[1] Power Optimised Aircraft, contract G4RD-2001-00601 under the European Communities Framework Programme for Research.