Abstract

More electric aircraft already demonstrated gains in term of safety, weight and thus fuel consumption. The all electric flight control architecture is presented as a major target for the next generation of aircraft to minimize the number of non-propulsive power sources and optimize efficiencies.

Strong of its experience on already in service electrical actuation (EHA and EBHA) on A380, UTAS (UTC Aerospace systems Actuation and Propeller Systems) is deeply involved in many projects with the European and national aeronautical community to continue to improve electrical actuation in the flight control perimeter. UTAS is moreover involved in Electro Mechanical Actuator technology programs for years like MOET, MODENE, A2015 and GENOME. These different programs will be shortly described and the key issues and next challenges of EHA and EMA for PFC applications will be highlighted.

Introduction

The global change in the electrisation of the aircraft has been progressively implemented since the 80’s. More Electrical Aircraft, as far as flight controls are concerned, started with the introduction of Electro-Hydrostatic Actuators (EHA). Objectives were to minimize maintenance operations on hydraulics and pneumatics circuitry and diversify power source to increase safety and reduce weight.

UTAS has invested in many projects to develop EHA technology, until the solution was implemented in the A380 commercial aircraft with all hydraulic Primary Flight Control actuators being back upped by an electric mode, either EHA or EBHA (Electric Back up Hydraulic Actuator).

Going now towards the All Electrical Aircraft a natural objective is also to mature the Electro-Mechanical Actuators technology with no more hydraulic disadvantage (internal leakages), further reduction of manpower for maintenance operation and further weight reduction expected.

This document will detail the two electrical technologies and the ongoing programs UTAS is involved in to improve electrical actuator design and reliability.

UTAS and the Electrical Aircraft

The first step in electrical actuator was made in 1990 with EGIDEII program. The objective was to design and manufacture an A320 Aileron EHA laboratory prototype (pressure 3000 psi). At this stage EHA performances and functionalities were demonstrated in laboratory conditions only (TRL4).

In the following CDVF program (Commandes de vol du future), UTAS targeted the objective to build an A320 EBHA aileron flight test prototype, able to withstand an endurance of 250 hours. CDVF prototype flight tests were successful (TRL5).

The major step was achieved with the COVAN project (1997-2000) where UTAS provided an Aileron EHA A320 and an Aileron EHA A330 (10kW) flight test prototype (TRL6-7). The design maturity was then demonstrated for future serial applications (A380).

Nowadays EHAs are implemented in A380 (Rudder EBHA, Elevator EHA and Aileron EHA) and 2 years ago UTAS was selected to provide entire flight control system on the Embraer KC390, including EHAs.

UTAS expertise is now improving with endurance and life experience feedback on aircraft.

UTAS is also involved in ACTIHOME (ACTionneurs Hydrauliques et électro-hydrostatiques OptiMisEs). This project is an aeronautical French direction initiative, partly funded, to work on EHA weight, cost and life potential improvement. It will allow designing and testing autonomous EHAs (without hydraulic connection to the Aircraft circuit) with new generation of hydraulic pumps and fluids. TRL 5 (Technology Readiness Level) is expected by 2018.

As detailed above, UTAS invested in many research programs have been necessary to mature EHA technology before introduction in service.
All electric aircraft architecture currently under study may lead to use also EMAs. For years, UTAS has also developed research programs aiming at developing the EMA technology.

For the first program Brite-Euram (1992) the aim was to demonstrate the feasibility of producing flight control EMA and the conclusion was positive, TRL4. Elisa program (1999) was more focused on performance analysis whereas MOET project (2006-2009) was centered more on the aspects of health monitoring and risk of actuator jamming reduction (tribology) TRL5.

**Fig. 2: MOET actuators**

MODENE project is currently in progress and will demonstrate the life potential of UTAS EMAs used in active or in damped mode (2 EMAs, one active, the other in damped mode). Endurance tests are ongoing and should be run until 2015, TRL5 is expected at the end of the project.

Latest program with strong involvement of the company is ACTUATION 2015. 53 partners from European aerospace company are involved and focused on reliability, cost and standardization of the EMA components.

The final demonstrator prototype will reach TRL5.

**Fig. 3: EMA standardization**

And currently, UTAS decided to develop a new generation of EMA (Aileron and spoiler) into GENOME R&T program with first EMA flight test on A320. GENOME will bring EMA technology to a TRL 7 for spoiler and aileron surfaces.

**EHA description and challenges**

An EHA is an actuator, which locally transforms an electrical power into a mechanical motion, via a motor, a hydraulic pump, a hydraulic fluid circulating through a hydraulic block and a power ram.

An accumulator is generally used to avoid any cavitation issue, to compensate for potential leakages and for thermal fluid retraction. Figure 1 below details the general EHA architecture:

**Fig. 1: EHA general description**

As mentioned above, EHAs are already installed on some commercial in service aircrafts (Airbus 380 for example). A certain amount of flight hours has been accumulated and technical feedback can already be analyzed on UTAS –APS units.

Although it demonstrated compliance to the expected functions and performances, EHA suffers from a lower Mean Time Between Failure (MTBF) than conventional servo-controls. The demonstrated weak points of the EHA are:

- the actuator motor and electronic thermal management,
- the pump life duration, which does not exceed few tens of thousands of Flight Hours (FH) for now, when aircraft life specification can exceed 150 000 Flight Hours,
- the electronic module reliability: even unpowered in normal mode on the A380, the electronic module is submitted to thermal cycling which is damaging.

Regarding the thermal management of permanently highly loaded surface like aileron, adopted solution up to now, on aircraft has been to force air convection around the units. This is an efficient solution for cooling the actuator but is very costly at aircraft level since it degrades the aircraft aerodynamics. Research activities are currently performed to optimize heating components cooling naturally and with dedicated devices.

Concerning EHA life duration, research activities are in progress to improve pump design and make EHA life potential competitive with servo-controls ones. Additionally, some studies are also done to make EHA autonomous and usable in front lane. Indeed, EHAs are installed on aircraft connected to a hydraulic circuit to allow periodic refiling of the accumulator to compensate leakages on one hand, and to renew fluid before it reaches an unacceptable
level of internal pollution on the other hand. Therefore, improving fluid quality is study axis.

**EMA description and challenges**

An EMA is an actuator, which locally transforms an electrical power into a mechanical motion, via a motor and a dedicated kinematics. EMA can be linear (linear output, see figure 2) or rotary depending on installation constraints and customer expectations.

**Figure 2: Example of a linear direct drive EMA architecture**

EMA challenges reside in managing risk of jamming, wear, lubrication, stability and thermal behavior. Maximize reliability, minimize weight and cost are always obvious requirements. And in the frame of the primary flight controls, additional specific functions are generally required such as load limitation, damping or blocking functions and bring also concerns and complexity.

Compared to hydraulic actuators or EHA, jamming is a more intrinsic risk for EMAs. This risk can be managed at system level, designing architecture with surface redundancy but also at actuator level. UTAS invested in studies to design jam tolerant EMAs. In the ELISA EMA for example, a clutch was introduced. More recently, UTAS designed and patented an innovative disconnection device appropriate for EMA, more compact and easier to integrate. However EMA additional weight, complexity and reliability shall be traded.

Depending on requirements, different EMA topologies can be used: direct drive EMA, geared drive EMA, linear or rotary EMA.

Whatever the topology, the motor is one of the first EMA key component. A lot of research activities are driven by UTAS to minimize its envelope and manage its heat dissipation, maximizing its performances. Special focus is oriented on winding and assembly optimization.

For linear applications, electrical motor rotary motion is converted to linear motion via a high efficiency screw device (ball or roller). Sizing, life prediction and jamming risk reduction are the difficulties associated to such device and UTAS has built a dedicated methodology to size and test these components. As detailed above, research programs like MODENE allow verifying correlation between theory and test results and demonstrate the high life potential of such components when correctly installed inside the EMA. For some applications, an additional gearbox might be necessary. We then talk about “geared” actuators. This actuator topology allows limiting motor torque but increasing its speed. It allows consuming less current and seems to be more easily manageable in terms of heat dissipation. On the other hand, geared EMA reflected inertia at the actuator rod end is high, since motor inertia must be multiplied by the square of the gear ratio. Its impact on flight control surface stability shall be deeply analyzed to avoid exciting surface mechanical modes.

Indeed, when surface is controlled with a dual actuator arrangement (aileron for example), an inactive or damped EMA is equivalent to a mass driven by the remaining active actuator as shown in the figure 3.

**Figure 3: Active/non-active configuration**

In this condition, frequency of the mechanical mode of the surface is inversely proportional to the root square of the EMA Inertia and can become sufficiently low to jeopardize surface stability. A very reliable damping device of the non-active actuator becomes then mandatory to ensure surface safety.

Without additional gear, actuator is called direct drive type. Direct drive EMA is simple (less parts), less prone to take backlash but consumes more current and generates more heat. With equivalent performances, its inertia is limited compared to geared EMA designs.

Rotary EMA (see illustration figure 4) does not include rotary to linear motion conversion (ball or roller screw). For flight control applications, it generally requires very high gear ratio and managing the compact gear box design, the inertia, the backlash limitation, the sealing and the risk of jamming are strong challenges to overcome.
A rotary EMA can be installed off hinge of a surface hinge line and be connected to the surface via a lever but can also be installed either on hinge, which can be an attractive option for thin wings aircrafts.

For the moment, EMAs are not so used on commercial aircraft flight controls with long life requirements. Very few feedbacks are already available.

Heating, wear, lubrication, backlash and jamming are identified as major challenges to be further mitigated to get sufficient maturity and envision using EMAs in front line on commercial primary flight controls architectures.

**Conclusions**

UTAS is an active contributor of the electrical actuation development for years. Strong of its experience accumulated in service and through its involvement in research activities, UTAS developed a strong knowledge and a clear vision of the way to go towards the all-electric aircraft.

Electrical actuators, EHA or EMA challenges are well identified. UTAS has defined its technology road map in order to address all identified blocking point and get the appropriate TRL for each technology brick included in the EHAs and the EMAs. On-going activities are progressing to improve reliability, weight and cost of electrical actuation to make it more complementary and/or competitive with current servo-controls.

In parallel of these research activities, UTAS put also a lot of energy developing health monitoring concepts, sensors and algorithms to improve the capacity to predict and correct failures before it happens.

**References**

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