

A Testing System for the Performance Evaluation of Fault-Tolerant Electromechanical Drives for Aircraft Applications

Giovanni Bucci^o, Fabrizio Ciancetta*, Edoardo Fiorucci^o

^oDip. di Ingegneria Industriale e dell'Informazione e di Economia, Università degli Studi dell'Aquila,
Via G. Gronchi, 18 - 67100 L'Aquila
Phone: +390862434634; Fax: +390862434403
{giovanni.bucci; edoardo.fiorucci}@univaq.it

*Dip. di Ingegneria Elettrica e delle Tecnologie dell'Informazione, Università di Napoli Federico II,
Via Claudio, 21 - 80125 Napoli

Abstract- In this paper, a testing system for the evaluation of the performance of innovative electromechanical drives for aircraft flaps is presented; it has been developed as a cooperation with the Umbra Group Aerospace. The research activity is focused on the design of the measurement system and on the development of the software for the measurement and the monitoring of mechanical, hydraulic and electrical parameters as well as the managing of the control system for the emulation of the load force opposing to the actuators movement. Innovative solutions based on the multithreading technique has been implemented, to guarantee the correct execution of the required tasks and the system synchronization. The obtained results shows that the different sections of the system are able to communicate and cooperate successfully, according to the required performance.

I. Introduction

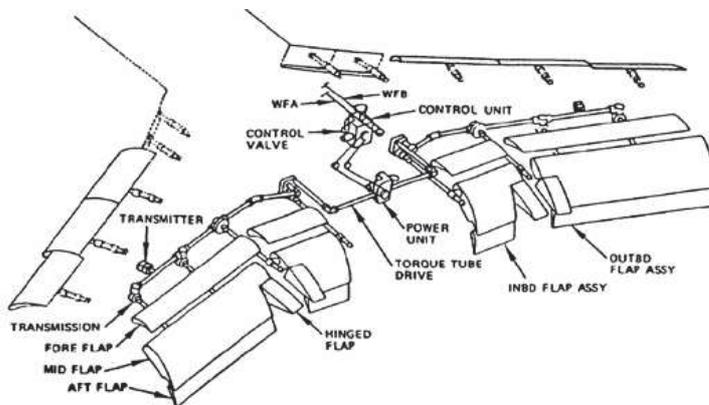


Figure 1. High Lift Systems.

Environmental protection and cost savings are the most relevant issues that today stimulate the aircraft manufactures to develop innovative solutions in designing the new aircraft generation.

Hydraulic drives are today progressively replaced with innovative electromechanical drives, allowing mass reduction and increasing the reliability. Major efforts are devoted to improve the performance of High Lift Systems (HLSs) [1], that are used to adapt the wing profiles to the airspeed and air density (Fig.1)

An innovative drive system has been developed, by adopting a couple of permanent magnet multi-phase synchronous motors, that have been designed to guarantee the required minimum performance even if a fault on one or two phases occurs[2-4]. The position of the two drives is controlled in parallel, to guarantee the required redundancy. The adopted solution avoids the implementation of complex systems for the tracking error managing, and it extends the fault-tolerant strategy of the multi-phase motor to the couple of actuators that drives each flap.

II. The system setup

The developed setup for the driving system testing is depicted in Fig.2; it consists of three elements: i) the PC panel; ii) the drive panel; iii) the testing bench. The PC panel is based on an industrial PC equipped with an LGA 775 Core 2 Quad Q 6600 @ 2,4GHz, 4 GB DDR 3, Hd da 500 GB and a NI PCIe-6323 DAQ board. The drive panel contains the control system, the DC bus supplier and two fault tolerant 5-phases inverters for the actuators driving. The control board ECU has been developed in two sections: ECU HIGH and ECU LOW. ECU HIGH is devoted to the generation of the path for the actuators, starting from the position profile created by the PC panel; ECU LOW manages the communication with the two drives, by sending them the data form ECU HIGH by

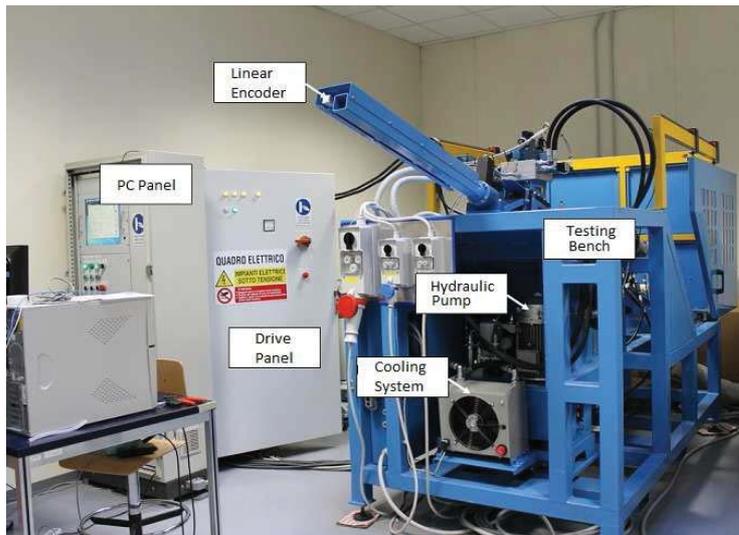


Fig. 2 : Testing bench

means of a high speed SPI bus at 6 Mbps.

The main elements composing the developed testing are: i) a hydraulic piston for the emulation of the aerodynamic force opposing the actuators movement; ii) a hydraulic circuit feeding the hydraulic cylinder; iii) a linear encoder for the measurement of the instantaneous position of the cylinder rod; iv) three load cells for the measurement of the forces on the cylinder and on the two actuators.

III. The hydraulic circuit

The testing bench emulates the aerodynamic load on the flaps, by supplying an opposite force,

according to the testing requirements. The force is obtained by means of a hydraulic cylinder, whose operations are controlled by an ad hoc oil-hydraulic circuit (Fig.3). Four kinds of valves have adopted, to control the oil flux and pressure during the testing procedures, guaranteeing the safety of the whole system: VEI, WRTE, DBEE and WREE valves. The VEI valves open and close the hydraulic circuit: these on-off valves are controlled by the measurement software and they are commanded if the measurement system detects a malfunction due to pressure overloads, or if one of the ECU units are in error; they are also commanded by the emergency button. The WRTE valve limits the maximum pressure in the hydraulic circuit; it is controlled by the software and it can be set according to the desired dynamic response of the hydraulic system. The DBEE are partialization valves: during a sudden variation of the circuit pressure, due to speed variation or to a load step emulation, they behave as hydraulic buffer. The WREE is a proportional valve, and it generates the required pressure difference between the two sides of a double acting hydraulic cylinder; the WREE is controlled with an analog input signal.

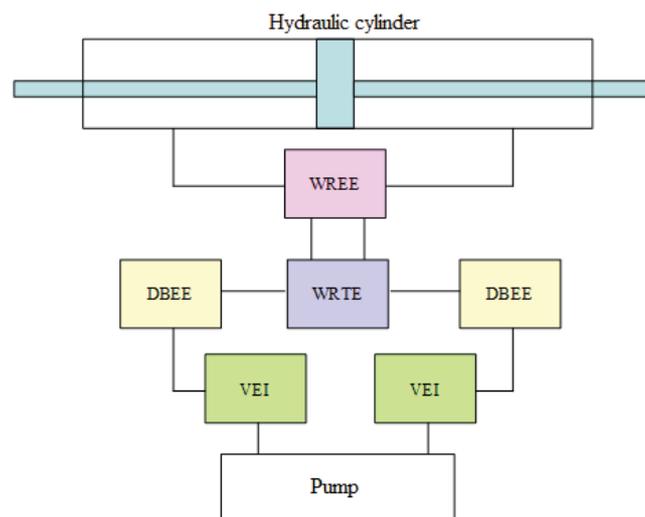


Fig. 3 : Block diagram of the hydraulic circuit

IV. The measurement system

For the experimental characterization of the system performance, we developed a measurement system embedded in the testing bench [5 - 7]; it performs: i) the monitoring of the mechanical and electrical parameters of the whole system; ii) the test configuration by creating the position profiles and the configuration/monitoring of the control parameters of each actuator; iii) the generation of the opposing force of the hydraulic piston

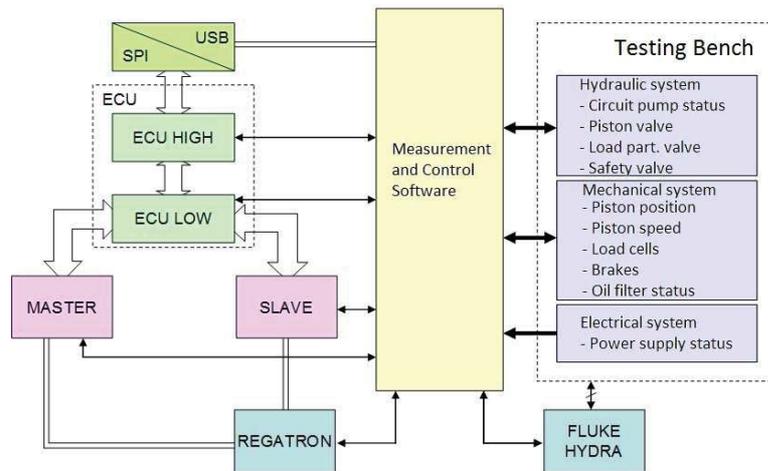


Fig. 4 : Block diagram of the measurement system

voltages transduction; DC and AC currents transduction has been performed with a set of LEM IT 150-S ULTRASTAB. These high performance transducers are needed because of both harmonic distortions and dynamic load variations that are typical of the considered testing conditions [8-11]. Two load cells CL 20 kN, one for each actuator, has been adopted; the force of the piston has been transduced with a 50 kN load cell model 3124; the output signals from the load cells have been conditioned with three TA4/2 amplifiers. The position of the piston is performed with a magnetostrictive linear position transducer Gefran model MK4-A.

V. The measurement software

The measurement software has been developed in the NI LabWindows CVI environment. Differently from other software for high level programming as LabVIEW, C#, VB.NET, DELPHI etc, the CVI allows: i) the development of user interfaces without intermediate software layers; ii) the implementation of multithreading based systems; iii) the adoption of event-based programming paradigm, implementing software and hardware interrupts; iv) the interface with data acquisition devices and external devices by means of .lib and .dll libraries provided by the manufacturers; v) the design of intuitive user interfaces due to its graphical controls and indicators libraries.

Because of the complexity of the system to be monitored and controlled, the software has been designed by implementing a multithreading approach.

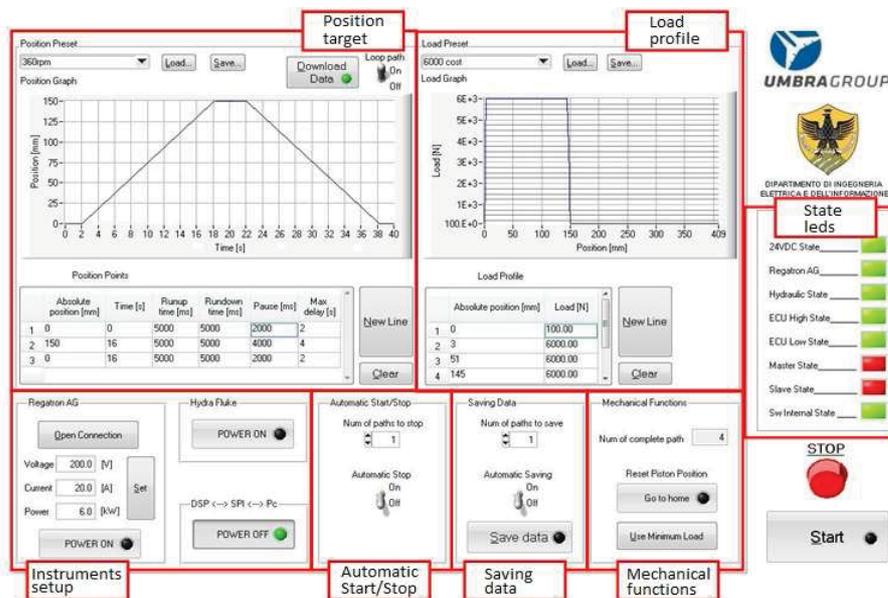


Fig. 5: User interface screenshot.

emulating the aerodynamic load of the flap.

The measurement system consists of the following devices: a NI PCIe-6323 DAQ board; ii) a Fluke Hydra equipped with 6 thermocouples for the monitoring of the system temperatures and the evaluation of the thermal stress, with a RS232 communication link with the host PC; iii) a Regatron 400 V, 32 kW DC power supply; iii) a SPI-USB TotalPhase Cheetah SPI Host Adapter for the monitoring of ECU HIGH, ECU LOW and of the two control systems (Fig. 4). A set of LEM CV 3-500 closed loop, Hall-effect voltage transducers, has been adopted for both DC and AC

multithreading approach. The developed threads have been devoted to: i) the PID control of the imposed force; ii) the acquisition of the data from ECU HIGH and ECU LOW by means of the SPI-USB converter; iii) the acquisition of the mechanical and hydraulic analog parameters; iv) the control of the of the DC power supply; v) the reading of the temperature data form the Fluke Hydra; vi) the communication

via RS232 with the DSPs of the actuators; vi) the synchronization of the output data of each thread; vii) the data storage; viii) the data visualization in the user interface; ix) the managing of the system diagnostics; x) the error handling; xi) the execution of the main thread.

The thread communication is based on Threads Save Queues: these are protected circular buffers managed by the operating system, allowing the data exchange among the threads and avoiding locks for the data access. A particular attention has been given to the emulation of the aerodynamic load performed by the hydraulic piston, by setting the force opposing to the actuator movement as a function of the required force-position profiles. A PID controller has been implemented in the software for the managing of the piston, and an high priority thread has been devoted to this critical process.

The user interface for the monitoring and control of the testing bench consists of two front panels: the first one configures the electrical and the control system, the second sets the testing parameters, manages the piston parameters and saves the data. In the first front panel (Fig. 5) the user can perform a preordained sequence to start the testing bench, by the following steps: i) the choice of the number (1 or 2) of drives to test; ii) the selection for the configuration file to set the both the DSPs variables and the initial configuration variables; iii) the starting of control logic circuits of the bench; iv) the start of the hydraulic circuit pump; v) the switch on of the electrical panel of the drives; vi) the DSPs configuration and run.

The second front panel contains some tabs; each of them is related to one thread. In the main tab (Fig. 4), the user can: i) set the parameters defining the position and force profile; ii) save and view the diagrams; iii) check the faults.

The remaining tabs (Figs. 14-17) allow the user to configure and to depict the behaviour of the actuators by means of a set of charts, by processing the data from the SPI: the visualized data give information about the mechanical parameter (load-position and speed-position charts), electrical parameters (DC bus voltage and current charts), hydraulic parameters (forces and pressure charts); the temperature charts show the data acquired by the Hydra datalogger. Each chart contains a set of led indicating the fault conditions related to all the parameters shown in each tab, to allow the user to check all the possible faults independently of the tab which has been selected.

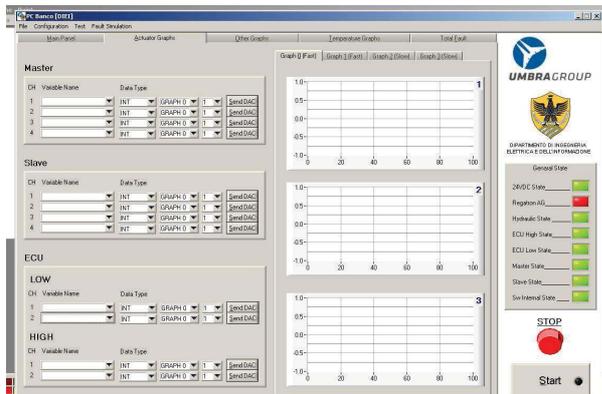


Fig. 3 : Screenshot of the actuators tab.

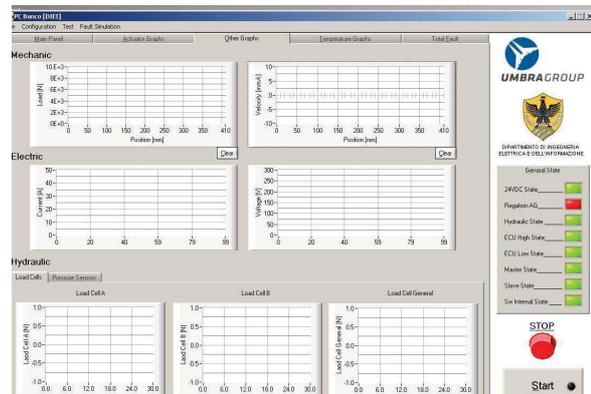


Fig. 4 : Screenshot of the charts tab.

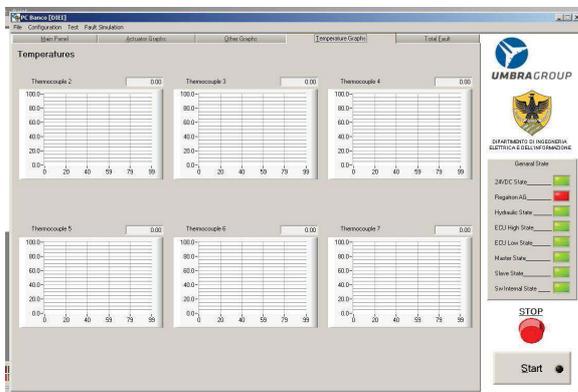


Fig. 5 : Screenshot of the temperatures tab.

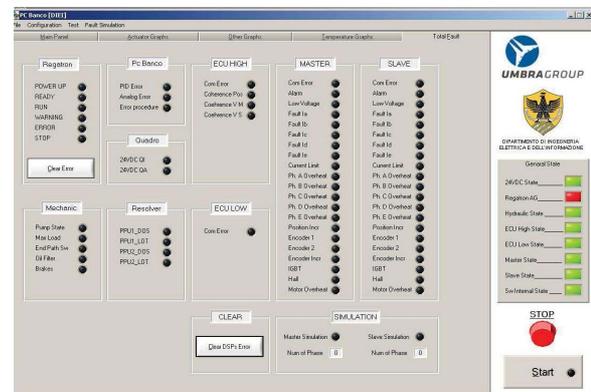


Fig. 6 : Screenshot of the faults tab.

VI. Experimental results

All the measurement results have been saved in the National Instruments TDMS format; some of them are shown in Figs. 6-9. Fig. 6 upper diagram depicts in per-unit the position profile of the two actuators (grey line for the Master one and red line the Slave one); green line and pink line represent the current absorbed by the Master one and by the Slave one respectively. In the same figure, the lower diagram shows the output of the load cells of the piston (red line), of the Master actuator (green line) and of the Slave actuator (blue line) when the load force has a rectangular shape.

In Fig. 7 the reference force profile and the measured data of the forces and the speeds of each actuator are presented. Fig. 8 shows a Comparison between the currents absorbed by the actuators working in parallel; Fig. 9 presents the experimental errors for the measured position, speed and load.

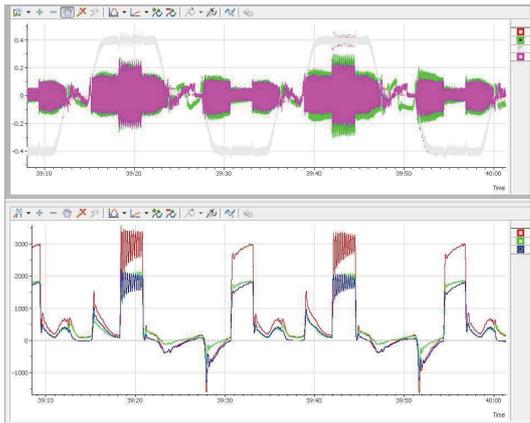


Fig. 6: Measured position profile, currents and forces of the actuators.

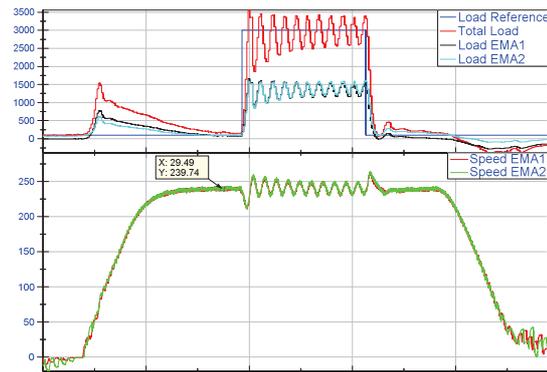


Fig. 7: Reference force profile and the measured data of the forces and the speeds of the actuators.

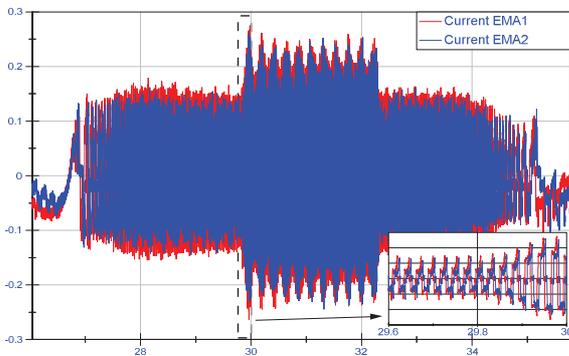


Fig. 8 : Comparison between the currents absorbed by the actuators working in parallel.

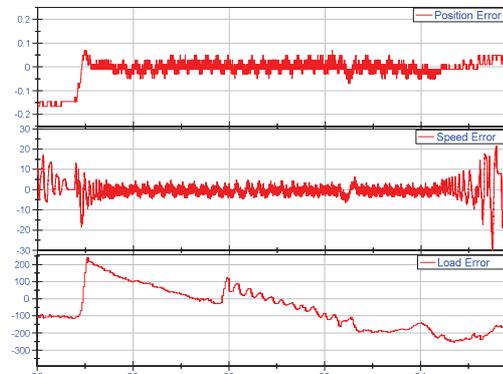


Fig.9 Errors for the position, speed and load.

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