

Automated testing system for electro-mechanical actuators used in aviation

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Abstract – This article presents an automated testing system for electromechanical actuators used in aviation. The paper describes the parameters and properties of the system and the possibilities of its use. Based on the data obtained from the system, a method for detecting actuator jam is proposed.

I. INTRODUCTION

In recent years, the concept known as More Electric Aircraft (MEA) has been gaining ground in aviation. The EMA concept aims to replace some hydraulic, pneumatic, and mechanical systems with electronic ones, which should bring many benefits such as lowering operating costs, increasing safety, reliability, and durability of some components [1]. At the same time, however, this trend brings new problems that need to be addressed. These include increasing the capacity of electricity grids, ensuring better energy distribution, developing new technologies for Integrated Health Management (IHM) and developing diagnostic methods that will be able to detect faults promptly [2].

One of the promising steps towards the objectives of the MEA concept is the use of electromechanical actuators (EMAs), which can be used in applications where linear motion is required. The integration of EMAs into aircraft systems brings new challenges, especially in the field of diagnostics. Despite their considerable reliability, not all failure modes and their manifestations are well known and described [3]. The current research is focused on the development of diagnostic methods that would detect these faults in time. The proposed methods are mostly based on data measured on actuators during operation (data-driven approach [4, 2]) or on simulations of models of individual actuators (model-driven approach [5, 6, 7]). For their design and verification, it is necessary to create test systems where these methods would be tested and evaluated under different operating conditions.

In this article, an automated testing system for EMAs is introduced. The system is composed of mechanical construction in which tested EMAs are mounted, the set of sensors used for control loop and the central unit which is responsible for the tests conducting including movement controlling in predefined modes, monitoring of actuators and data acquisition.

II. TESTING SYSTEM DESCRIPTION

A. Block diagram

The block diagram describing the connections of the individual parts of the system is shown in Figure 1.

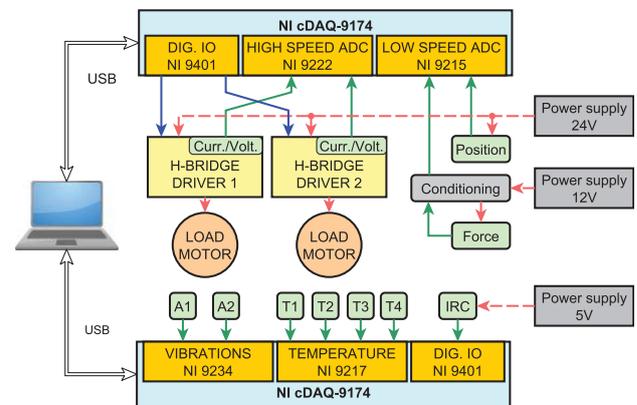


Fig. 1. Block diagram of the testing system

The system is controlled from a computer connected to two NI cDAQ - 9174 via USBs. Both units are equipped with three plug-in modules and are controlled by a program from LabView. The upper NI cDAQ - 9174 chassis serves as the primary unit for controlling the rig and the elementary data collection. It includes the NI 9401 module which provides two-way digital communication with eight digital I/O connectors. It is used to control the direction of rotation of the actuator motor and to generate a PWM signal. NI 9222 and NI 9215 modules are used to measure a voltage with a resolution of 16 bits. The NI 9222 allows synchronous measurements of up to 500 kS per channel, and it is used for a high-speed recording of the current and voltage waveforms. The motor current is measured on the output pin of the control unit whose voltage corresponds to the current flowing through the bridge. The motor voltage is measured on the voltage divider that is connected directly to the power output of the control unit. The NI 9215 allows synchronous measurements up to 100 kS per channel, and It is used to measure slowly changing signals such as position and force.

The secondary NI cDAQ - 9174 chassis include modules for additional measurements. The NI 9234 measures signals from two integrated electronic accelerometers (A1,

A2) with the sampling rate up to 51.2kHz. Additionally, each channel of the module is equipped with the anti-aliasing filters that automatically adjust to your sample rate. The NI 9217 is a resistance temperature detector (RTD) module that provides per channel current excitation. Up to four sensors can be connected to the module with the sampling rate up to 400 Hz between all channels. The NI 9401 in the secondary chassis is used for processing of TTL signals from Incremental Rotary enCoder (IRC). All additional sensors can be placed anywhere on the test system as needed. The basic configuration for one actuator includes measurement of ambient temperature, the temperature of motor cover, gearbox and casing of rod, vibrations of motor and gearbox and revolutions of the motor.

The diagram also includes power blocks with 5, 12 and 24 V power supplies.

B. Conditioning

The force sensor uses a conditioning circuit, which is responsible for a generation of stabilized voltage for the sensor itself, and also it amplifies the output signal level. The conditioning block circuit is depicted in Figure 2. The

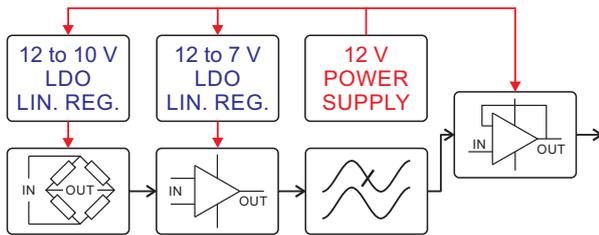


Fig. 2. Conditioning block circuit

circuit is composed of 12 V power supply that powers two low-dropout (LDO) linear voltage regulators and voltage follower. The linear voltage regulators are responsible for providing stabilized voltage. The stability of the voltage is essential, especially for the force sensor. The force sensor is composed of strain gauge with the output rated at 2 mV/V of full scale. Consequently, with the 10 V input, the output of the sensor is 20 mV under full load. This voltage value is not just too low for further processing, but it is easily affected by noise. Therefore, the signal must be properly amplified and cleared of noise. The output of the strain gauge is amplified by the rail-to-rail precision instrumentation amplifier. This type of amplifier has a high common-mode rejection ratio (CMRR) about 115dB, which is indispensable for common-mode noise reduction. The amplifier is powered by the 7 V output from the second linear voltage regulator. The output signal from the amplifier is then filtered by the first-order RC low pass filter. Parameters of the filter can be changed by the replacement of the R or C component as needed. The basic configuration of the filter has a cut off frequency of about 500 Hz. The

output of the filter is connected to the voltage follower to prevent excessive loading of the filter. The circuit is placed in the metal box, and all cables of the entire system are shielded adequately in order to suppress noise as much as possible.

C. Mechanical construction

The mechanical construction of the testing system consists of a frame, a linear guide and mounting parts of individual components such as actuators and sensors. The structure is designed so that it can be changed depending on the requirements of the tested objects. The frame is composed of lightweight aluminium sections, which have in cross-section of 40x40 mm. The construction itself has the shape of a cuboid with dimensions of 680x488x560 mm, and it is crossed by a bulkhead used for mounting the linear guide and mechanical connector of an EMA. The linear guide is intended to ensure the linear movement of the actuator. It consists of two cylindrical rods, on which the trolleys fixed by an aluminium profile move. The guide length is 600 mm, and the carriage height is 120 mm, which allows a range of movement of almost 480 mm. The mechanical construction with the linear guide is depicted in Figure 3.



Fig. 3. The detail of linear guide

The construction allows two types of stressing of EMAs. The first is with the static weight. In this case, the weight is placed on the top of the movable part of the construction. The load is scalable thanks to the different weights of the metal blocks that can be placed on each other. The static weight represents load in a constant direction. The actuator is stressed when pushing the load and relieved when pulling. Holder for the static weight can be seen as an upright rod attached to the carriage in the top of Figure 3.

The second type is the controlled load achieved by the secondary actuator. In this case, a secondary actuator is controlled based on the pressure sensor and creates artificial weight for a tested actuator. This arrangement allows stressing tested actuator in both directions. The

force is also scalable based on secondary actuator performance. The proper operation of the artificial load has been achieved thanks to a flexible element which is placed between the load actuator and the construction. This element is necessary for suppressing shocks that are caused by the rigidity of the construction and actuators. Bidirectional damping spring has been designed for this purpose. The spring is made of polylactic acid (PLA) plastic and has been printed on the Prusa 3D printer. The damping spring is depicted in Figure 4.



Fig. 4. The detail of the damping spring made of PLA

D. Motor power driver

Each EMA is connected to its own power control driver in the form of a fully integrated H-bridge. The driver uses as input PWM signal defining the power applied to the motor and signals that determine the direction of engine rotation and braking. The unit operates in the 4-28 V range and can provide output current up to 15 A at a maximum PWM speed of 20 kHz. The power transistors have a very low on-state resistance of 70 m Ω . The unit is also equipped with protection elements such as overvoltage, short-circuit protection, thermal fuse, current and power protection or inductive voltage diodes.

E. Electromechanical actuators

Two types of actuators with similar characteristics can be mounted to the current version of the system: The TA 2 actuators manufactured by Timotion and the DSZY1 manufactured by the Drive-Systems Europe Ltd. Each actuator consists of a DC motor with the commutator and permanent magnets, gearbox and actuator body, which includes a piston driven by a screw drive. The actuators parameters are shown in Table 1.

F. Sensors

The system is equipped with four main sensors that are monitoring the position of EMA, the load applied to EMA,

Table 1. Actuator parameters

Parameter	TA 2	DSZY1	Units
Voltage of motor	24	24	V
Maximum load	120	150	N
Maximum speed at 24 V	33-44	40-45	mm/s
Motor speed at 24 V	4200	6000	RPM
Stroke	150	200	mm
Gear ratio	5:1	5:1	-
Typical Current	1.2	2	A

the electric current flowing through the actuator's motor and the voltage at the input of the motor. The position sensor is mainly used as feedback of the control loop of the controller. The test system uses Honeywell's SPS-L225-HALS sensor. This magnetic sensor with analogue output measures non-contact position using a permanent magnet attached to the moving part of the structure. The sensor range is 225 mm, with a resolution of 0.05 mm. A bidirectional force sensor is installed between the actuator mount and the moving part of the structure. The sensor is used both to measure the actuator force acting on the moving part of the structure, and also as feedback for the control loop. The system uses sensor 151 S-Beam Load Cells from manufacturer Honeywell with a range of ± 500 N. The electric current of the motor is measured at the output of the motor power driver, which contains a current to voltage converter. The output voltage corresponds to the current flowing through the H-bridge. The voltage on the motor of the actuator is measured using the voltage divider, which is connected between the output of the H-bridge and the input of the motor. The divider was designed that it is possible to measure up to ± 32 V. In this range, the output of the divider stays under the 10 V, which is limit for the differential analog input of IN 9222. The system is equipped with additional sensors such as temperature sensors, vibration sensors, and incremental rotary encoder. These sensors can be placed in the system as needed. There are four miniature Pt100 4-wire RTD (NB-PTCO-155) sensors that can be attached to any part in the system. The range of temperature sensors is -30 to 200 $^{\circ}$ C. For the vibrations measurement, there are two Bruel&Kjaer 4507-B-004 accelerometers that have vibrations range 0.3 - 6000 Hz up to peak 70 g. Additionally, these sensors are also TEDS (Transducer Electronic Data Sheet) compatible. For the measurement of the motor revolution, there is an Incremental Rotary enCoder (IRC). The used HEDR-5421-EP111 is the two-channel optical incremental housed encoder that has a resolution of 200 PPR (Pulses Per Revolution) per channel.

G. Control and Data Acquisition

The test device is controlled by a program designed in LabView. The program allows working with actuators in

three different modes of operation: basic motion, position control and load control. Depending on the mode of operation, it is possible to set the duration of operation, the frequency of PWM. The basic motion mode allows selecting the actuator, the direction of movement and duty cycle of the PWM. In the position control mode, which uses information from the position sensor, it is possible to select the actuator and use the function generator to define the motion profile, period length and limits of the motion range. There are four profiles to choose from: sine, rectangular, triangular and saw. The movement is controlled by a software PID controller. In load control mode, the position control mode is extended by another adjustable PID controller that simulates a load using the force sensor information using a second actuator. In this way, it is possible to execute a predefined motion profile by one EMA which will be loaded by second EMA. The program allows data acquisition from all inputs from the NI 9222, NI 9215, NI 9234, NI 9217 and NI 9401 modules, which it stores in a predefined location with a timestamp indicating the date and time of recording.

H. Fault injection

The system allows non-destructive and destructive fault injection. Non-destructive fault injection is a simulation of conditions that correspond to some types of faults. For instance, the change of the electrical parameters of the motor, such as the increase of coil resistivity, can be simulated by placing the low-value resistor in a series with the motor. Alternatively, the deterioration of lubrication can be simulated by gradual drying of lubricated parts. These types of simulated faults can load the actuator extensively, but they should be reversible without permanent damage.

Destructive fault injection is performed by the physical intervention to the actuator. It is possible to artificially inject the faults that are typical for EMAs such as broken teeth of the gearbox or shorted or interrupted winding in the motor. The example of the permanent fault injection is depicted in Figure 5. These types of faults permanently damage the actuator, and therefore it is necessary to perform sophisticated tests of the EMA before the fault is injected. The data measured before and after fault injection can be compared, and based on the character of the fault, the methods for fault detection can be designed.

III. RESULTS

The proposed system was used to design a method for jam detection. The actuator jam fault was simulated by a high load at which the motor could not move. The electric current waveform is shown in Figure 6.

The plot shows considerable noise in the blue waveform. The noise is caused by a 16 kHz PWM switching frequency, which is suppressed by filtering (red waveform). The oscillations in the curve are caused by commutator



Fig. 5. Broken teeth fault injection

spikes, which occur when the brush breaks the contact with the commutator sector connected to the energized winding.

The actuator jam occurred at around the time 0.5 sec. It can be detected by the steep increase of current and the disappearance of commutation spikes. The algorithm compares commutation spikes detected by a moving variance with the instantaneous current value. Detected jam fault is highlighted by a grey region.

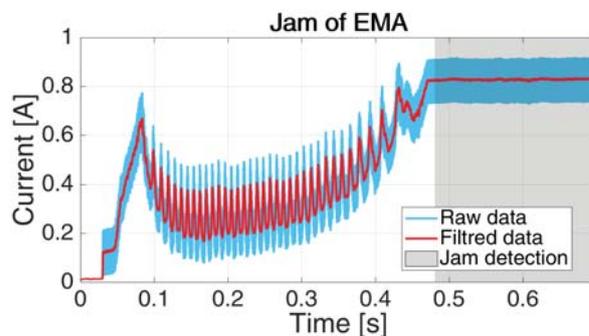


Fig. 6. EMA jam fault detection

IV. CONCLUSION

This paper introduces an automated system for testing electromechanical actuators used in aviation. The test system was designed for the development of fault detection and diagnostics methods. The system allows testing of various types of linear actuators, measuring parameters during their operation, the introduction of artificial faults, analyzing fault modes, and designing and testing methods for fault detection and diagnosis.

The system offers automated controlling of the movement of two actuators along predefined paths. Paths are generated by functions such as sine, rectangle, triangle, or saw. The position, force applied to the actuator, the current flowing through the actuator motor, and the voltage at

the input of the motor are recorded during the tests. Also, secondary parameters such as vibration, temperature, and motor revolutions can be added to the measurement. The actuators can be stressed with the static load, or it is possible to use the second actuator as an artificial load. This configuration makes it possible to run the stress tests under conditions to which the actuator would be subjected to normal operation. The functionality of the system was demonstrated in the design of the method for detecting the actuator jam.

ACKNOWLEDGMENT

This work was supported in part by the Grant Agency of the Czech Technical University in Prague, under grant Nos. SGS20/071/OHK3/1T/13 and in part by TACR, project no. TH04010237.

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