ACTIVELY CONTROLLED TRAILING EDGE FLAPS WITH ELECTROMECHANICAL ACTUATION

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Abstract

The present paper studies Active Rotor Control for helicopters. It is shown that Individual Blade Control (IBC) concept is more preferable for the purposes of rotorcraft vibrations reduction. There described electromechanical pre-prototype actuator and active flap control model test simulator designed by the Mil Moscow Helicopter Plant. Active flap control model and electromechanical pre-prototype actuator test data obtained at the Mil Moscow Helicopter Plant test facilities are provided. The obtained results show that electromechanical actuator of the type could be applied in the active rotor control systems for both existing and future rotorcraft.

1. INTRODUCTION

The stringent requirements to levels of the helicopter vibrations are more stringent now, and that is the reason of development of the Active Flight Control systems concepts. The most promising of them now are active main rotor blade control by Higher Harmonic Control (HHC) and Individual Blade Control (IBC).

The main distinction between HHC concept [1] and IBC concept [2] lays in the blade controls arrangement. According to the HHC concept the blade control actuation is placed underneath the swashplate upon the non-rotating elements the helicopter structure. The IBC concept presumes that servo drivers are above the swashplate, i.e. on the rotating components of a helicopter such as rotor hub and rotor blades. The principle drawback of the HHC is that it includes some fixed control frequencies limitation which depends on the number of the main rotor blades. Despite those limits, the HHC now demonstrates 5-6 dB of the noise reduction and up to 90% of the vibration decrease, the IBC concept is considered to be more promising due to absence of the HHC shortcomings and also the further potential for the swashplateless helicopter design.

The practical results of the IBC systems development were demonstrated up to now in the flight tests performed in Germany on the CH-53 helicopter with the use of electrohydraulic actuators embedded within blade control rods, and on the BO105/BK117 [3] helicopters with the use of the active trailing edge flaps controlled by the piezoelectric actuators.

The research activities pertinent to the active control problems in the Mil Moscow Helicopter Plant started in 2009 and aimed to a medium class helicopter (of Mi-8 type). The analysis revealed that the use of the electrohydraulic actuators embedded within blade control rods is not practical in view of the system extreme complexity. The use of the piezoelectric actuators was also not possible because of dramatically small actuation travel. So their use is limited to light helicopters (BK117 blade chord is about 150 mm vs. 550 mm for Mi-8).

Based on the study results, electromechanical actuation (EMA) concept of the active trailing edge flap was chosen.

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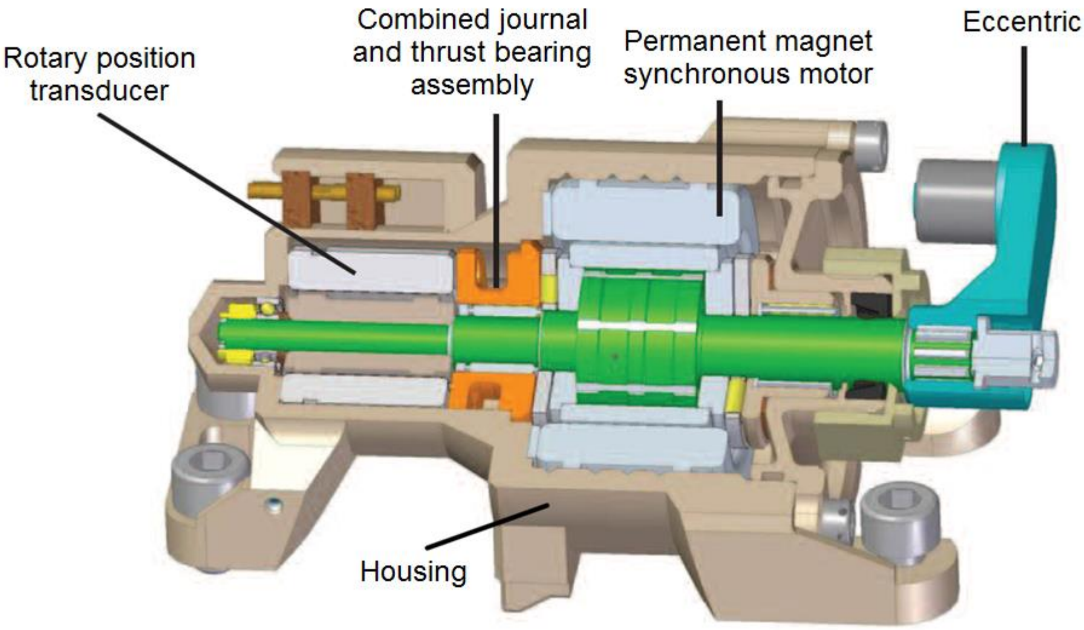

Fig.1. EMA 3D Model

2. MIL MOSCOW HELICOPTER PLANT’S RESEARCH ON ACTIVE TRAILING EDGE FLAPS WITH ELECTROMECHANICAL ACTUATION (EMA)

EMA development was in close cooperation with the Joint Stock Company “DIAKONT” (St.Petersburg, Russia).

Mil Moscow Helicopter Plant Design Bureau R&D studies on vibration reduction problem started in 2009. The Mi-8 helicopter main rotor mathematical model provided a significant help to the research of the influence of the polyharmonic signal introduced into the main rotor blade cyclic pitch control with various harmonics, amplitudes and phases. The results achieved were read at the 38th European Rotorcraft Forum (4) and at the 69th American Helicopter Society Forum (5), also the related research article was published (6).

Based on the results achieved and works above, there was refined technical specification for the active flaps EMA. As a result “DIAKONT” was able to develop electromechanical actuator for the rotor active trailing edge flaps control (Fig.1).

EMA comprises the following components:

High-torque permanent magnet synchronous motor with hollow rotor, featured by high dynamics, great over-torque capability and high performance factor. High accuracy rotary position control is provided by digital invertor with vector pulse-width modulation;

Crank is an output lever which connected with the motor rotor. It transforms motor rotor rotation into the stroke of the telescopic connecting link directly connected with the flap;

Rotary position transducer (resolver type) serves:

- to define rotor angular position;
- to generate control command to motor phases;
- to detect output rod absolute coordinates.

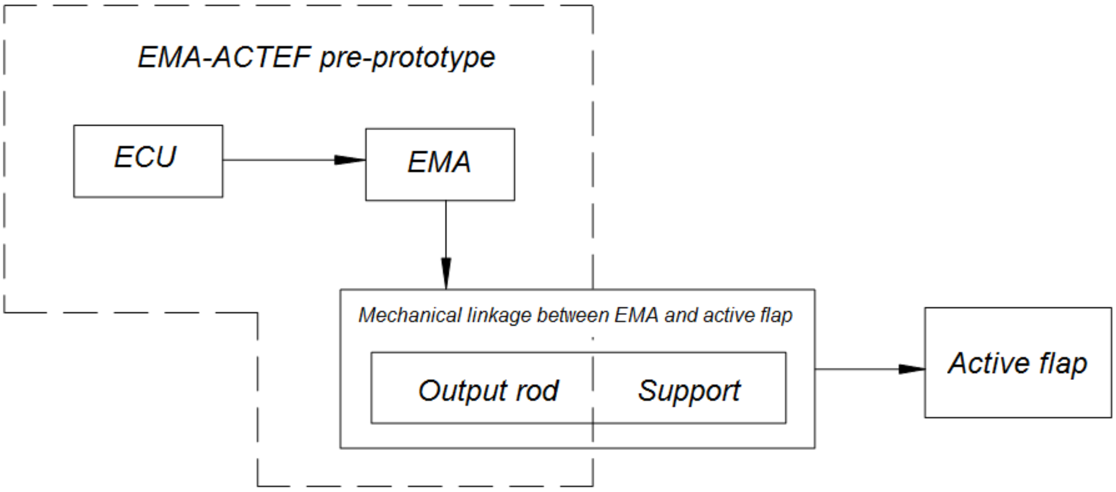

Fig.2. EMA-ACTEF pre-prototype block scheme (ECU - Electronic Control Unit)

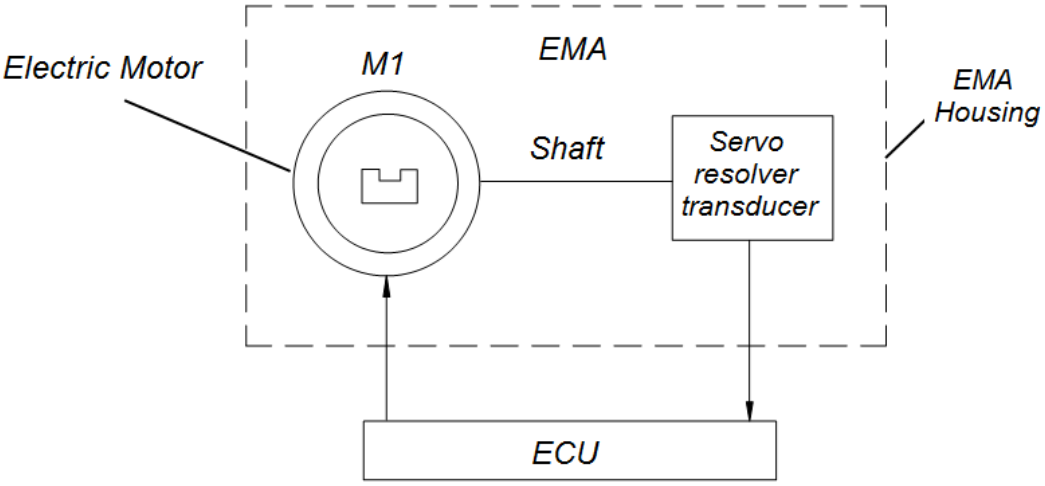

Fig.3. EMA block scheme

EMA specifications:

- Rated torque – 2 Nm.
- Frequency – 20 Hz.
- Deflection range - +/- 55°.
- Accuracy - +/- 1%.
- Weight of EMA – 330 g.
- Dimensions – 50x50x90 mm.

EMA-ACTEF assembly consists of:

1. **EMA** is meant to rotor edge active flap simulator control.

2. **Electronic Control Unit (ECU)** is meant to transform control command from airborne control to EMA.
3. **Output rod** is meant to connect EMA pre-prototype with the push link mounted on the active flap. It is an integral part of the mechanical linkage.

EMA-ACTEF pre-prototype architecture

Fig.2 represents EMA-ACTEF pre-prototype block scheme.

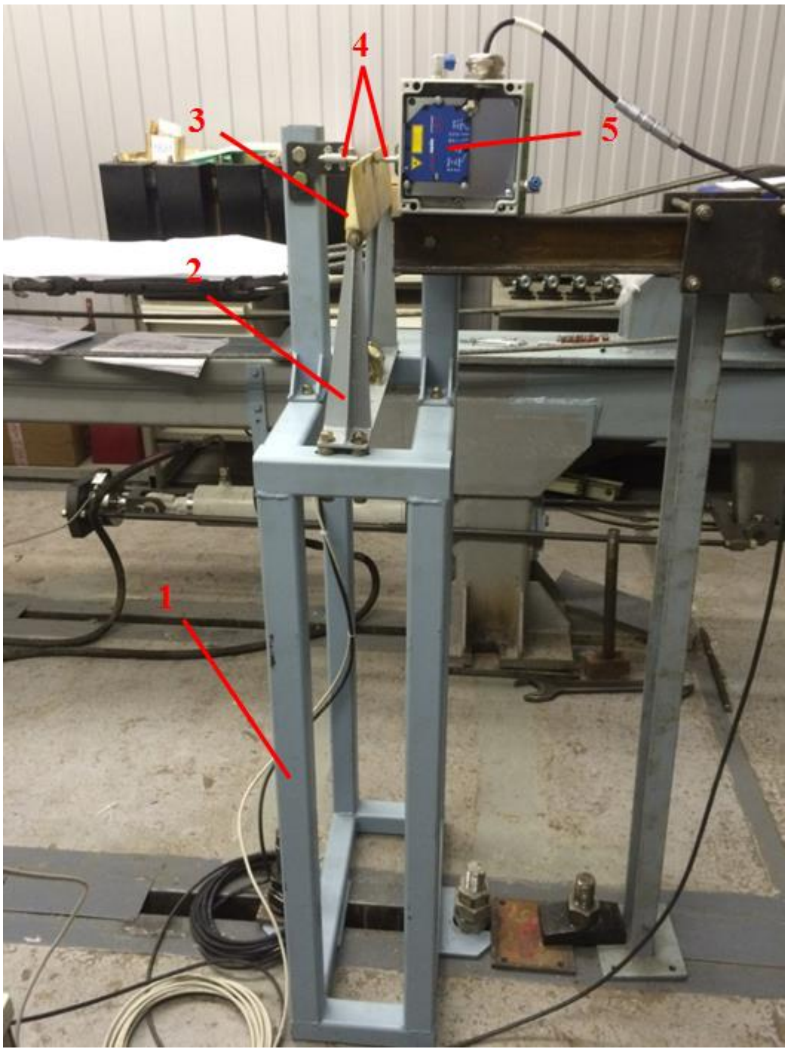

Fig.4. EMA-ACTEF Electromechanical Actuator Test Simulator Layout

Fig.3. shows the EMA block scheme.

EMA consists of the following components:

- Electric motor Robodrive 38×12 (17) including rotor and stator;
- Motor angular-position sensor (further referred as servo resolver transducer) Resolver RE-08;
- Driving Shaft;
- Housing.

Servo resolver transducer provides operation of the electric motor rotor angular-position control loop.

Output rod (push link)

Output rod (push link), being an integral part of the mechanical linkage between EMA and active flap, connects EMA pre-prototype with support, mounted on the blade active flap. Mechanical linkage transmits EMA angular movement to helicopter rotor blade active flap.

2.1. Active Flap with Electromechanical Actuation EMA-ACTEF Simulation

2.1.1. Simulator

To provide EMA-ACTEF bench running Mil Moscow Helicopter Plant designed special test simulator. Fig.4 depicts its layout.

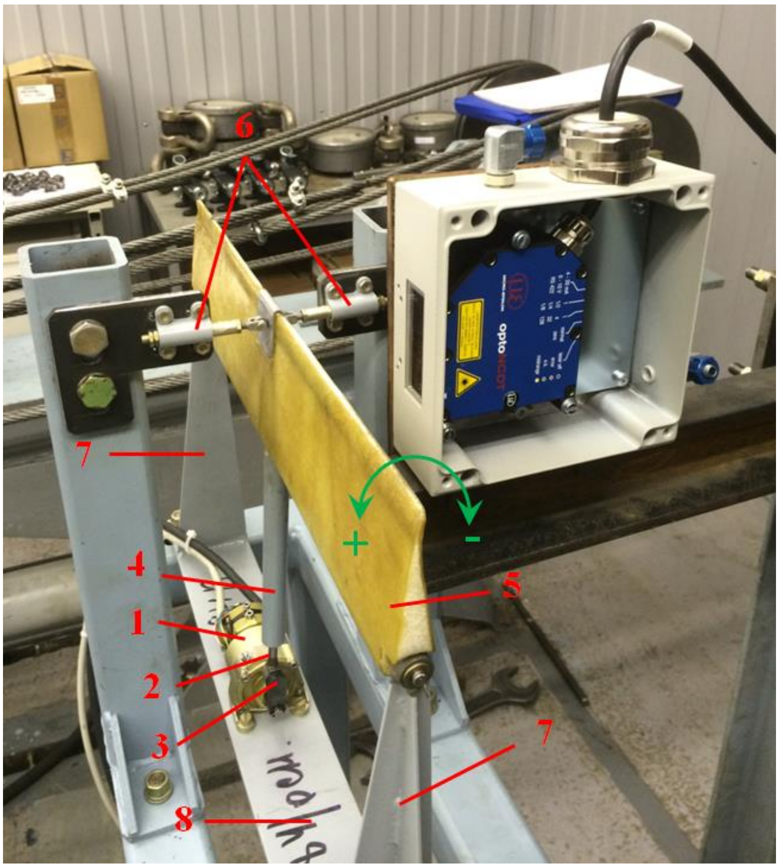

Fig.5. P-shape frame with EMA-ACTEF active flap

Simulator comprises bed frame ***1*** on which P-shape frame ***2*** is mounted. P-shape frame simulates spar and ribs of the helicopter rotor blade trailing edge. EMA-ACTEF is mounted on horizontal plate of the frame ***2*** which imitates the spar. Active flap (AF) ***3*** is hinged between rib imitators. To simulate aerodynamic hinge moment forced on active flap **3** there were installed feel spring mechanisms ***4*** on bed frame ***1***.

Laser sensor optoNCDT ***5*** serves to measure flap trailing edge linear displacements. Flap aerodynamic force is simulated by feel spring mechanism. While flap deflection was +/- 5°, feel spring mechanism created linearly varying torque +/- 0.2 kgf•m. P-shape frame's design with active flap and electromechanical actuator EMA-ACTEF installed on it is shown on Fig.5:

1- Electromechanical actuator EMA-ACTEF
2- Output rod
3- Eccentric
4- Pushing link
5- Active flap
6- Feel spring mechanism
7- Ribs simulator
8- Spar simulator

2.2. Measured parameters

1) Active flap oscillatory amplitude, mm.

To convert flap trailing edge linear displacement into angular deflection with regard to hinge axis let us use the formula:

$$\delta_{\mathrm{AF}} = 57{,}3\ \cdot \mathrm{arctg}\left(\frac{\Delta l}{L}\right) \qquad (1)$$

where δ_{AF} – active flap deflection angle, mm;
Δl – flap trailing edge linear displacements, mm;
L – distance between flap hinge axis and optoNCDT laser sensor data point.

2) Amperage by EMA-ACTEF electric motor.

3) EMA-ACTEF output shaft torque.

2.3. Test modes

1) Separate control signals applied to the flap as the following: the 1st (3.2Hz), 2nd (6.4 Hz), 4th(12.8 Hz), 5th(16Hz), 6th(19.2Hz) harmonics of the main rotor RPM with deflection amplitudes from ± 1° to ± 5° (in 1° increments). All control commands were recorded by means of laptop computer.

2) Joint control signals of the 4th and 6th harmonics of the main rotor RPM but with different amplitudes and phases applied to the flap. Also, all commands were recorded by the notebook.

2.4. Test data

Fig. 6-9 show the flap deflection records with the 1st, 2nd and 5th harmonic frequencies with different amplitudes and the 4th and 6th harmonic superposition.

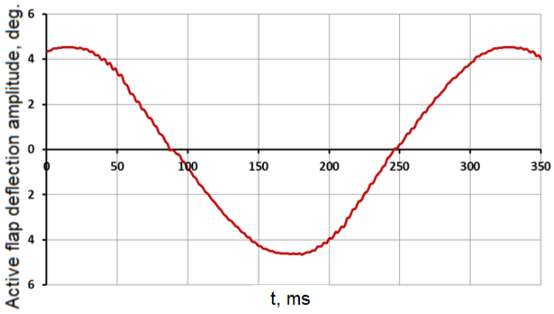

Fig.6. The 1st harmonic, 5° amplitude

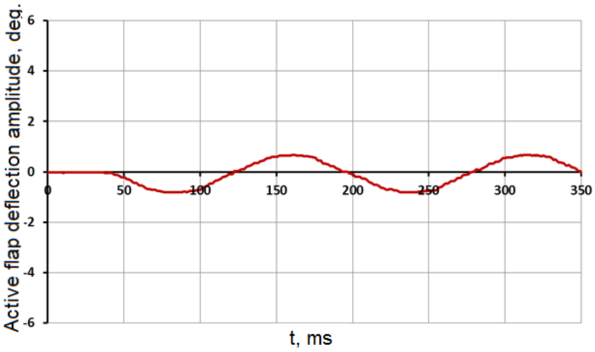

Fig.7. The 2nd harmonic, 1° amplitude

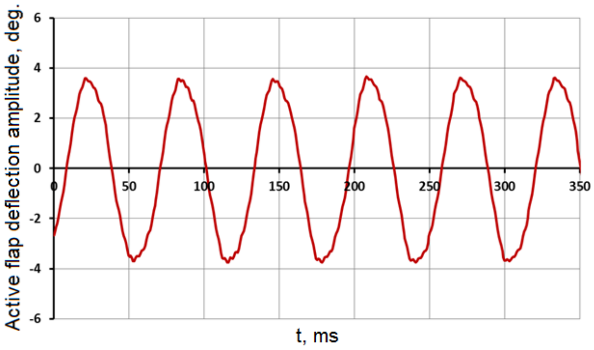

Fig.8. The 5th harmonic, 4° amplitude

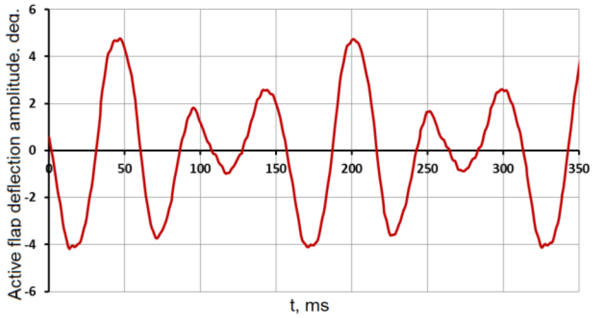

Fig.9. The 4th (2° amplitude, 0° phase) and the 6th (3° amplitude, 90° phase) harmonic superposition

Fig.10 shows EMA output shaft torque and the 6th harmonic time connection.

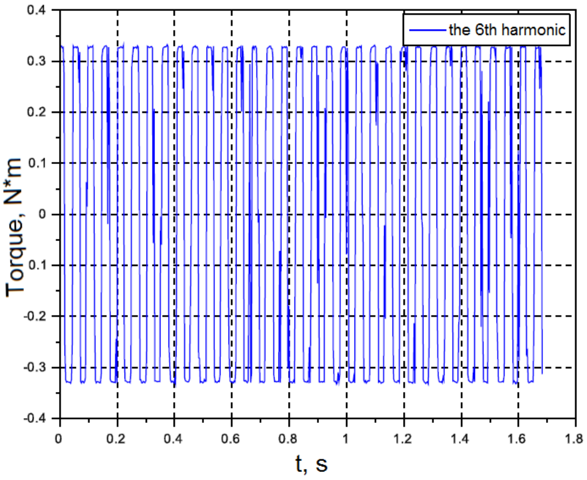

Fig.10. EMA output shaft torque and the 6th harmonic time relations

Fig. 11 and Fig.12 depict amplitude frequency response for input signal amplitudes of 1° and 5°.

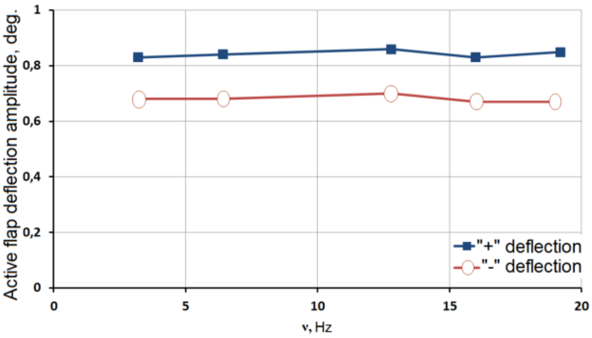

Fig.11. Active flap amplitude frequency response for input signal of 1°.

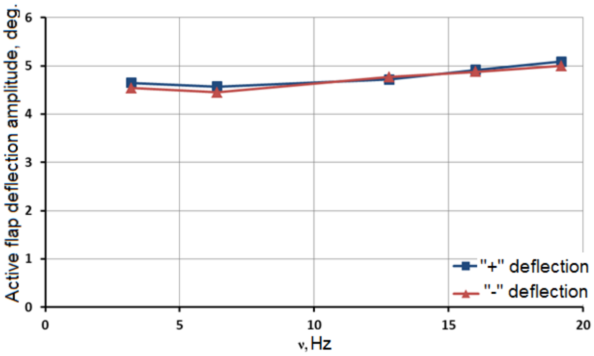

Fig.12. Active flap amplitude frequency response for input signal of 5°

2.5. Conclusions

The present study shows that individual rotor blade control (IBC) concept is more attractive for the purpose of rotorcraft vibration reduction. Design of the helicopter rotor blade active flap EMA actuator was introduced. Also, there was described simulator developed by the Mil Moscow Helicopter Plant. It was created for the testbed running of the active flap electromechanical actuator (EMA). Test data revealed that EMA of the type could be used in Active Rotor Control systems for both existing and future helicopters and rotorcraft.

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