# THE USE OF ELECTRIC DRIVES ON BOARD OF AIRCRAFT

**František Adamčík – František Adamčík, jr.**

The improvement of the means of flying is associated with the introduction of a number of aggregates and electromechanisms. The significance and direction of board electric drives development in recent years has greatly influenced the development of more electric aircraft types. Electric drives and mechanisms of various board aggregates must operate reliably in difficult working conditions.
K e y w o r d s: aircraft, electrical drives, electromechanisms,

## 1 INTRODUCTION

The gradual improvement of the means of flying is associated with the introduction of a number of assemblies and mechanisms where different functions are based on consumption of mechanical energy. This development is mainly caused by the increase in speed, altitude and air mass of flying equipment. Gradually, aircraft control systems have improved. Flights under difficult conditions became possible, which facilitated the work of crews who can focus their attention on other tasks. Implementation of the retractable landing gear contributed to reducing the drag, thus, further increasing the speed of flight and reducing the landing speed. Use of landing flaps improved landing conditions, the speed limit in dive flights of combat aircraft. Aerodynamic shields, full use of aircraft engine performance in all flight regimes, and further improvement of the flight characteristics brought about the establishment of mechanisms for changing the angle of attack of rotor blades, etc.

## 2 ELECTRIC DRIVES ON AIRCRAFT BOARD

Number of units and mechanisms and the increasing number of elements for their operation has continued to grow. These ones differ in terms of use, nature of loads and work schedules. All elements and links of an aircraft branched system serving to ensure the movement owing to its control are called energy (power) drives. The individual parts and the whole complex of the energy drive is an organic part of the aircraft itself, with direct impact on flight characteristics. Therefore, all processes in power drives are closely related to the actual flight, i.e. operations performed by the crew in the conditions the aircraft is located. Therefore, the energy drive is always necessary to analyse the aircraft as a whole and not only its individual parts. Depending on the used type of primary energy, the energy drive can be – electric, hydraulic, pneumatic or combined.

The use of electric drives on aircraft board has the advantageous properties, for example - easy usage and automation of control processes, the small effect of low temperatures, a simple transfer of power from the electromechanical transducer to the working mechanism, high reliability and buck up [2, 3].

One of the first types of electric drives used in the aircraft is an electric starter for starting piston aircraft engines. Manual starting replaced them but did not meet the terms of maximizing the performance of aircraft engines and their need for fast, reliable and easy start, especially in combat aircraft. Electric motors also found use in systems as pump (oil, fuel) drives, lifting and transporting equipment, landing lights, weapons, etc.

Application of electric drives expanded with the introduction of jet aircraft engines. It was necessary to use much more powerful starters (dynamo-starters) and even with the possibility of their feeding from onboard batteries. Increasingly precision servo-drives started to be used for e.g. radar antennas, stabilization of platforms in the system control modes of aircraft engine operation and systems of photo equipment. Due to increased fuel consumption, the gradual emptying of fuel tanks (without changing the centre of gravity) is provided by automated software systems pumping fuel during flight.

The enlarged aircraft size and the transition to supersonic flight speeds affected the strength needed to control the surfaces and overcome them without fatigue in a long-term flight. This gradual increase in demands primarily

on the reaction speed of electrical drives has begun to show their limitations:
The ratio of the electromagnetic torque of an electromotor $M_{em}$ to its volume V (mass m) cannot exceed (for the insulating material) an allowed range:

$$M_{em} = \frac{P}{\omega} = \frac{c.D^2.l.\omega}{\omega} = k_1.V \quad (1)$$

where c - the machine constant, D, l - diameter and length of the electromotor armature, ω - angular velocity, $k_1$- simplistic constant

It follows that the moment of inertia of the rotating parts of the motor J, acceleration and hence the reaction rate in terms of volume (size) are practically limited.

$$J = \frac{M.D^2}{4} \quad (2)$$

$$\frac{d\omega}{dt} = \frac{M_{em}}{J} = \frac{k}{D^2}$$

Therefore, the basic control system of the aircraft started to use auxiliary power circuits - mostly electro-hydraulic servomechanisms with a combined mechanical and electrical input signal. The advantageous power to weight ratio, suitable dynamic properties and high reliability of operation have caused that the concept of electro-hydraulic power drives to be up to these days.

The significance and direction of development of onboard power drives in recent years greatly influenced the development of new aircraft types and the possibility of so-called AEA all electric aircraft with a (electric) power system for all main and auxiliary circuits. Implementation of this concept is based on the fact that from the previously used systems such as electric, hydraulic and pneumatic power only electric one is capable of providing power for all assemblies and mechanisms without energy conversion. Their atypical structures (with variable wing configuration) and a number of auxiliary surfaces are more demanding on implementation of their own management system. Transmission of all signals and power as well as power members are already electrical.

The idea of full electrification equipment of aircraft will be accomplished using new designs of electric motors and significant increase in the reliability of electrical and electronic components and circuits. Using new magnetic materials for new types of electric motors helped achieve the high power density and good dynamic properties comparable with hydraulic drives. The rotor of the permanent magnet can be made with a high coefficient of l/D (length to diameter), which allows to achieve high levels of speed during starting and braking.

Replacing the hydraulic power by electric one, among other things, has eliminated complex piping, energy converters, various valves, manifolds and hydraulic accumulators. Their mutual comparison with respect to the basic parameters (mass, reliability, energy required, technical features, easy construction, and effects of environmental working conditions ...), shows that in some ways the electric power is more advantageous than hydraulic one and vice versa.

In general, electric motors have the greatest advantage in energy efficiency that results from their operating principle - "performance as needed“ compared with hydraulic drives - "continuous function". Other factors are also taken into account, such as:
a) hydraulic drives have usually less weight in the same conditions of using power than electric ones,
b) output of power drives is a crucial factor for their comparison.

Therefore, it seems advantageous to compare them according to weight characteristics regarding to the reliability of system operation and their usage. Integration of electro-mechanical rudder actuators to basic facilities is still associated with solving issues of reliability, backup, security, power, etc. A possible compromise solution to the problem of power drives e.g. hydraulic rudder actuators with direct electromechanical drive of gate valve node. They enable simplification of the structure and combined utilization of both the advantages of electro-mechanical drives and benefits of long and good use of hydraulic drives. In order to reduce the required performance in the electromechanical power drives with short-run (e.g. in the landing gear system), the potential use of a flywheel or other energy accumulators is considered. The approach to designing flight control systems and aircraft as a whole has largely changed due to replacement of hydraulic drives by electric ones and realization of all electric aircraft. The main requirement is to increase flight safety.

## 3 WORKING CONDITIONS OF ELECTRIC DRIVES ON AIRCRAFT BOARD

Electric drives and mechanisms of various board aggregates must operate reliably in difficult weather conditions. Their working conditions with respect to the development of aircraft are constantly changing (especially increasing of the speed and operational level) and are different from those working electric drives used in ground equipment.

Differences can be characterized by the following factors [1]:

a) The large scale of changes in atmospheric conditions in dependence on altitude

With the change of height the properties of the atmosphere also change. The temperature decreases with increase in height of 5-7 °C per each kilometre in the range from about 11 km to 20 km its value does not change, is - 56.5 °C. The pressure and air density also decrease. In the mid-latitudes the pressure at the ground is about 100 kPa and decreases with the height - at 12 km is 6 times and at 20 km is 16 times lower than close to the ground.

The air density is proportional to the temperature. It decreases with the growth in height, for example at 12 km is less than 4 times and at 20 km is about 14 times than close to the ground. The humidity also changes. The temperature in the air may have only a limited amount of water vapour, for example at 15 °C the saturation limit is 12g/cm³ and at - 20 °C only 1g/cm ³. At the 9-10 km altitude, the water vapour in the air is no longer present. Decreasing density and increasing of ionization (due to ultraviolet radiation from the sun and cosmic rays) increases the electrical conductivity of air which reduces the dielectric strength – e.g. at 15 km its value is 2.5 times less than close to the ground. Notwithstanding the decrease in temperature with increasing altitude, the relative thermal conductivity of air due to the decrease of its density decreases. Such changes in the atmosphere have a mainly negative influence on the process of commutation in direct current motors of conventional design and cooling conditions of electromechanisms which are located outside the sealed cabin.

Decrease in temperature adversely affects the properties of lubricating grease in the bearings and reducers, thus changing the moment of electric motor resistance and increases the friction losses. The electrical wire resistance also changes its value, for example at +50 °C for Cu and Al wires about 1.4 times greater than at -60 °C. Reducing the dielectric strength of air and hence the insulation resistance the period of electric arc burning is extended e.g. at U = 24V = at height of 15 ÷ 16 km is doubled in relation to the time close ground. Increase of air electric conductivity and deterioration of cooling conditions leads to requirements of necessary enlargement of the geometric dimensions of equipment and thereby reduction of the relative energy burdens.

b) Effect of air speed

Flights at supersonic speeds also at reduced ambient temperatures may cause the so-called aerodynamic heating of the surface of front (exposed) parts of aircraft. The temperature of air brake current (T) depends on the atmospheric air temperature ($T_A$) and Mach number (M)

$$T=T_A. (1 + 0,2 .M^2) \quad (3)$$

If the mean temperature of 25 ÷ 30 km at M = 1 is 10 ° - 25 ° C so at M = 4 it can reach up to 400 °C, leading to deterioration of electrical properties and cooling conditions.

c) Effect of mechanical force

The aircraft equipment is adversely affected by flight dynamic shocks, vibrations, aerodynamic forces and overloading. Vibrations can be caused by imbalance of an aircraft engine or slight imbalance of a propeller. Their frequency varies in the range of 0,5÷2500 Hz with an amplitude of up to 2,5 mm. Overload resulting in different modes of flight (takeoff, landing, shooting, rocket launching of military aircraft) can reach 12 g and more. This may cause spontaneous connection (disconnection) contacts in the control circuits, winding wires break, greater wear of bearings and shafts in electromechanisms, affecting the work of the electromagnets and springs.

d) Chemical effect

Chemical effect of fuel vapour, oil and hydraulic mixture causes particularly corrosion of materials and reduction of their electric strength. This is reflected for example by oxygenation of commutators of DC machines and carbon in them, increased erosion of material contacts, changing the properties of lubricants, etc.

e) Influence of position in space

Flying means together with their equipment can take different positions in the area. The construction of aggregates and mechanisms (design of bearings, commutation apparatus) must be adjusted with regard to this fact.

## 4 CONCLUSION

Specific conditions of work and also the importance and complexity of the performance of the functions of energy drives on the aircraft determine difficult tactical-technical requirements which must be met together with all equipment. The main are:

1) reliable and trouble-free operation under all conditions of flight,

2) the minimum weight and dimensions without the limitations of their functional reliability,

3) high mechanical, electrical, thermal strength and chemical resistance,

4) safety in terms of fire (explosion),

5) optimum drive considering the full use of aero tactical aircraft properties while maintaining flight safety - effective energy indicators,

6) independent work on changing weather conditions, position in space, air speed and acceleration with sufficient life

7) suppression with regard to work of the radio and navigation equipment and flight control and measuring instruments

8) simple use, quick installation and maintenance.

Along with these essential requirements the additional – specific ones may be required. Depending on application, for example, some drives must reliably operate at positive but also negative static loads, power circuits of actuators to start the aircraft engines must be adapted to economical energy consumption, reliability regarding the impact of environmental conditions is of the paramount importance in power drives, and it must meet their solid construction, protection against moisture, etc. An essential parameter in automated electric drives is the static and dynamic stability which itself is affected by the type of the transfer from electric motor to the working mechanism.

From the facts mentioned above it follows that in many cases the requirements are different or even contradictory, e.g. maximum mechanical strength and minimum dimensions and weight, etc. Therefore, energy drives of aircraft aggregates and mechanisms must result from both optimal and compromise solutions considering all the requirements, the reliability under all conditions of flight, in particular.

BIBLIOGRAPHY

[1] ADAMČÍK, F.: Základy leteckých pohonov I.. Košice, VVLŠ SNP Košice, 1988.

[2] DUB, M.: Elektrické vybavení letadel II., Brno, Univerzita obrany, 2009. ISBN 978-80-7231-697-7.

[3] SOPATA, M. - BRÉDA, R. - SOTÁK, M.: Missile development using modeling and simulation methods. In: MOSIS 2005, Modelling and simulation of systems : Proceedings of 39th spring international conference. Ostrava: 3/2005, p. 63-68. ISBN 80-86840-10-47

AUTHOR´S ADDRESSES

František Adamčík, Prof., Dipl. Eng., PhD.
Faculty of Aeronautics
Technical University of Košice
Rampová 7, 041 21 Košice, SR
e-mail: frantisek.adamcik@tuke.sk

František Adamčík, jr. Dipl. Eng.
Faculty of Aeronautics
Technical University of Košice
Rampová 7, 041 21 Košice, SR
e-mail: frantisek.adamcik.2@tuke.sk