МОНІТОРИНГ, ДІАГНОСТИКА ТА КЕРУВАННЯ ЕНЕРГЕТИЧНИМИ ПРОЦЕСАМИ ТА ОБЛАДНАННЯМ MONITORING, DIAGNOSTICS AND MANAGEMENT OF ENERGY PROCESSES AND EQUIPMENT

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MODELING OF AIRCRAFT STEERING CONTROL SYSTEM WITH TRACTION ELECTRIC DRIVE BY USED AN ADAPTIVE FUZZY CONTROLLER

One of the main tasks of the last two decades is to find ways to optimize energy consumptions for aircrafts. The commercial aviation business is increasingly using environmental monitoring systems and electrical control by using AC and DC tires. One of the trends in the development of aircraft control systems is the replacement of hydraulic and pneumatic systems with electrical ones. The aerospace industry and airlines are interested in performing steering operations without major engines. This operation method allows to save fuel, reduce brake wear, eliminates towing and achieve decreasing of environmental pollution. In the future it is necessary to implement electric steering using a traction drive (TD) based on a synchronous motor with permanent magnets (PMSM). This system is powered by an available auxiliary power unit or other sources such as fuel cells or batteries. This study presents a highly efficient electric steering system as a modern solution for improving the ground operations of modern aircraft powered by main engines. The system was investigated using steering profiles for takeoff and landing. The study determined the effectiveness of its use for steering. The influence of external factors and the change of parameters of the electromechanical system of wheel with an elastic tire were investigated. The results of modeling the dynamic processes of an electromechanical system containing elastic links in the conditions of parametric perturbations confirmed the robust stabilization of dynamic control quality indicators based on the laws of fuzzy logic.

Keywords: *control system, traction electric drive, aircraft steering, fuzzy regulator.*

Introduction

The main factor that has influence for the choice of electric steering system (ESS) is the size of the aircraft. Several studies on the topic of electric steering have focused on small or medium-sized commercial aircraft [4,5]. Therefore, in order to define the maximum possible performance of possible applications of ESS, one of the large modern medium-sized aircraft was selected for the study. Considering huge mass of large aircraft, the ESS with current performance for traction engines and especially energy saving system devices are not viable. The decision to select one of the largest medium-sized aircraft for today and determine the parameters of the ESS for it requires the use of traction engines. These engines have similar characteristics to the most powerful engines currently available on the market.

In this work, a commercial Airbus A321 aircraft was selected for the study.

Purpose and objectives. The aim is to achieve the required quality parameters of the steering system based on the development of adaptive control algorithms. These indicators should provide an increasing of dynamic accuracy and stabilization of characteristics of the electrotechnical complex of electric drive by change of parameters, elasticity, external perturbations and loading at the uncertainty conditions.

Material and research results. One of the most important stages in the development of a fully functional system is the process of determining the appropriate design requirements. This general statement is generally accepted and applies to any product or system development process. In order to determine the requirements for a satisfactory design of the ESS, 20 aircraft motion profiles were recorded using a GPS device**.** These profiles are called drive cycles or steering cycles. In the first stage, 10 take-off and 10 landing motor movement profiles are evaluated to analyze the performance of conventional aircraft steering. Next, for medium-sized aircraft, performance parameters are selected in accordance with the conditions that satisfy the kinematic performance requirements of most available drive cycles.

In the period from December to June for different types of conventional steering operations, speed profiles had been recorded at the time when the aircraft were moving on the ground before take-off and after landing. Control profiles were registered by a GPS device at various airports in North America, Europe and Ukraine. A total of 20 steering cycles were recorded. The places where the cycles were recorded are given in table. 1.

Table 1 – Available steering cycles

Airports take off cycles	Airports of landing cycles
Calgary, Canada (1)	Brussels, Belgium (2)
Dallas / Fort Worth, USA (2)	Calgary, Canada (1)
Frankfurt am Main, Germany (1)	Dallas / Fort Worth, USA (2)
Lviv, Ukraine (1)	Frankfurt am Main, Germany (2)
London Heathrow, United Kingdom (2)	London Heathrow, United Kingdom (1)
Boryspil, Ukraine (3)	Boryspil, Ukraine (2)

In fig. 1-8 four profiles of the steering cycle are shown. Examples of take-off cycles and their corresponding GPS-observation are described in Fig. 1-4. In Fig. 5 and Fig. 6 two different landing cycles are shown. The aircraft steering cycle at Boryspil Airport begins with the delay phase before the shock. From 25 to 80 seconds the aircraft is in reverse move (low speed phase). The aircraft remains in place after disconnecting the tractor from the nose gear of the aircraft. This is because the main engines must be warmed up before starting normal operation. The aircraft exits the gate from the place where the main engines reach the desired temperature. It marks the starting point for the take-off process (after 220 s). At this stage, the aircraft moves solely due to the main engines. The aircraft steers to the runway without a stop, but with frequent changes in speed, which lead to changes in acceleration and deceleration.

As soon as the plane reaches the runway, it stops to wait for permission to take off from the tower. Once the permit is issued, the aircraft enters the take-off stage and leaves the airport. This steering cycle is a good example of the take-off steering process without stopping forward move.

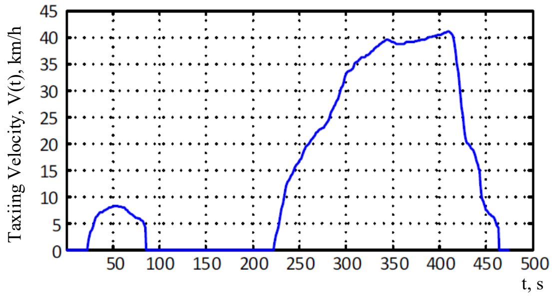

Fig. 1 – Boryspil Airport, Ukraine –
Take-off Drive Cycle № 2

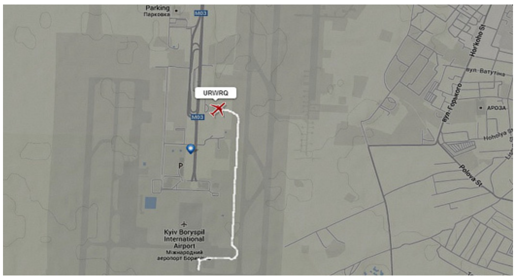

Fig. 2 – Boryspil Airport, Ukraine –
Take-off Drive Cycle № 2

The take-off steering cycle at Lviv Airport (Fig. 3, Fig. 4) is an example of a cycle with several stops before take-off. After the initial countdown (from 40 to 120 s), the planes stop at several intersections.

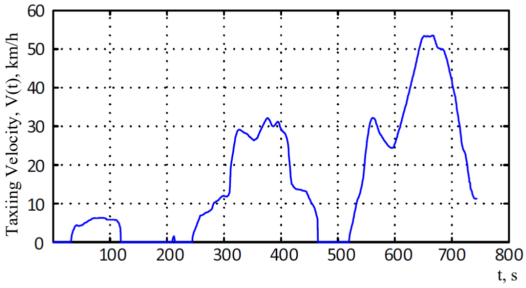

Fig. 3 – Lviv International Airport, Ukraine –

Fig. 4 – Lviv International Airport, Ukraine –
Take-off Drive Cycle

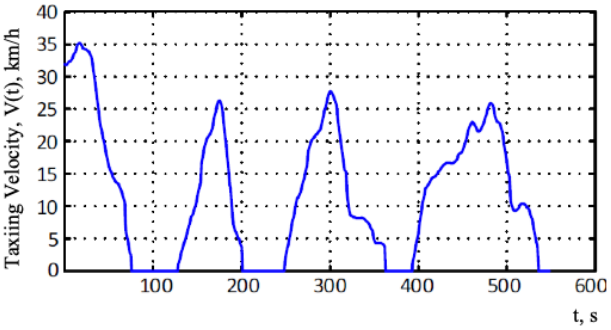

Fig. 5 – Dallas / Fort Worth Airport, USA – Landing Drive Cycle № 1

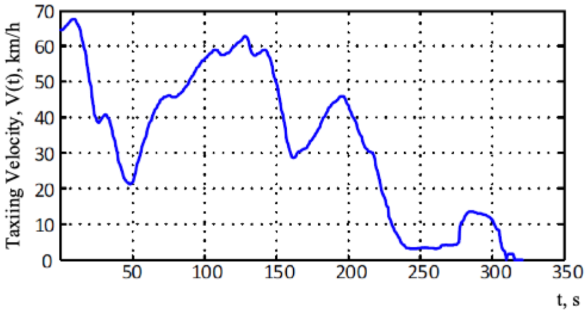

Fig. 6 – Boryspil Airport, Ukraine – Landing Drive Cycle

In fig. 5 and 6 two different landing cycles are shown. The taxiing cycle at Dallas Airport is an example of a cycle with frequent stops to reach a maximum taxiing speed of close to 30 km/h. The landing cycle at Boryspil airport, in contrast to the Dallas cycle, during the steering phase is a smooth profile without stops, reaching a high speed of up to 60 km/h. The only existing stop in the Boryspil landing profile is the place where the aircraft reaches its final position in front of the terminal (after 310 s).

Fig. 7 – Dallas / Fort Worth Airport, USA – Landing Drive Cycle № 1

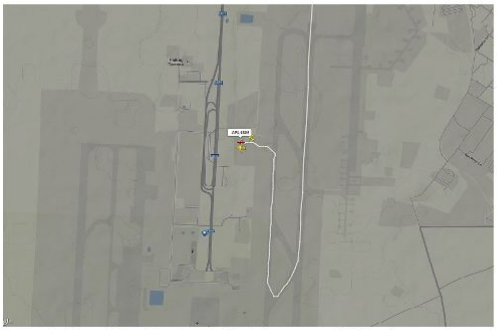

Fig. 8 – Boryspil Airport, Ukraine – Landing Drive Cycle

Analysis of the results of graphs for these four application cycles shows that steering can perform different profiles depending on the airport infrastructure and ground traffic conditions. The presence of steering profiles allows to perform a detailed performance analysis. These results of analysis can be used to determine the performance requirements of the ESS.

Optimization control of electric drive in the general case includes two interrelated tasks: 1) implementation of optimal by certain criteria rules change of controllable variables and formation setting influences corresponding to these changes; 2) reproduction of controllable variables of the setting influences by the least error.

The first task concerns optimization by control mode, the second – optimization by transients. Improving the quality of electric drive control systems by known methods is hindered by a wide range of factors that change the parameters' value of the electromechanical system (EMS) during operation. Therefore, there is a need to create a control system that would prevent the impact on the plant of destabilizing factors and would be insensitive to change. The usage of fuzzy regulators can solve this issue. They provide the implementation of the specified dynamic regimes. Fuzzy control can perform the function of adjusting the action of a traditional regulator that will increase the accuracy of the signal by a given speed.

A simplified model of the PMSM speed control circuit is used for modeling of elastic electromechanical system. The current circuit must be used in the system. General structure of speed regulation is shown in fig. 9.

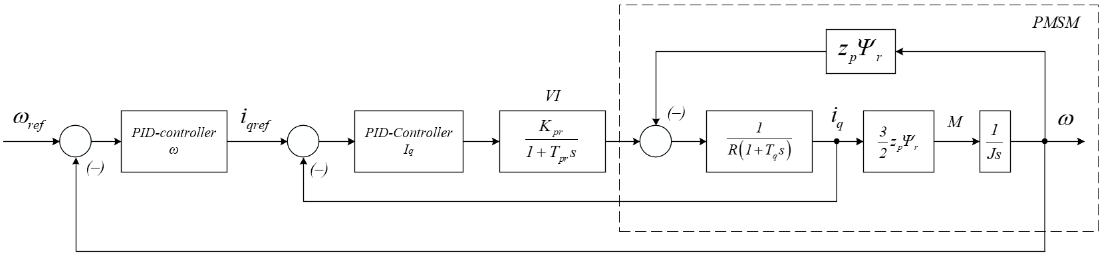

Fig. 9 – Simplified model of SDPM speed control:VI – voltage invertor

The simulation model in the Simlink environment is shown in Fig.10.

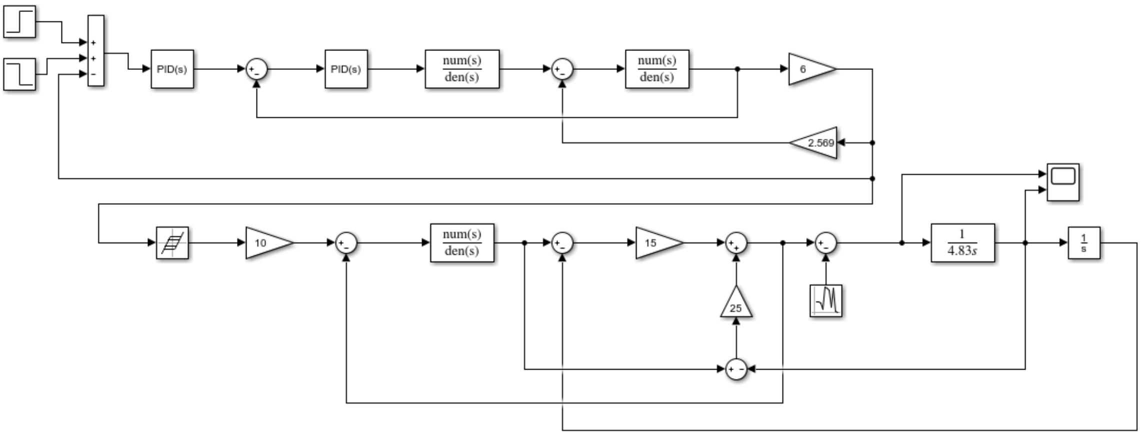

Fig.10 – Simulation model of a multi-mass EMS wheel of an aircraft chassis

Fig. 11 shows the transients in speed and torque. Speed adjustment is 14%. The transient process by the moment shows that the engine can go into generator mode under the influence of external influences. This is unacceptable during the operation of the system at the initial stage of aircraft movement.

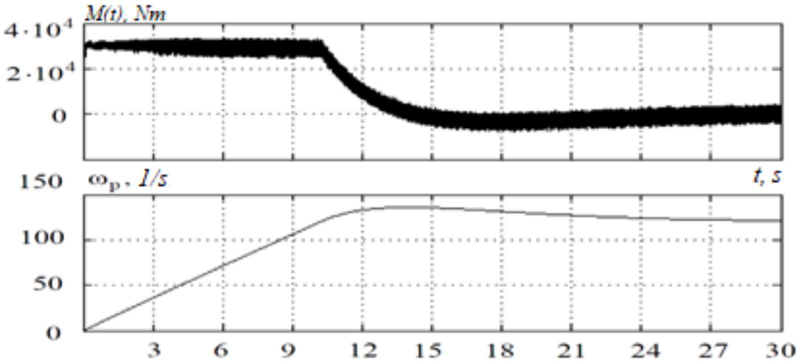

Figure 11 – Transients by speed and torque

It is necessary to consider that during the operation of the system its parameters may be changed. That is why an adaptive fuzzy controller (FC) with two input signals of the difference between the set and current wheel speeds should be used as the speed controller. The block diagram of the control system using the adaptive fuzzy controller (FC) [6] is shown in Fig. 12.

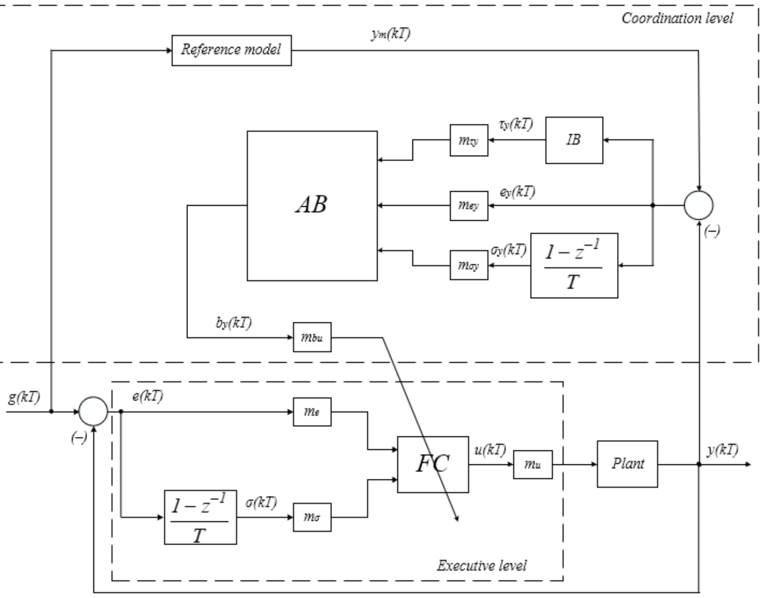

Figure 12 – The structure of the control system with adaptive FC:AB – adaptation block; IB – integration block

Adaptive FC combines coordination and executive control levels. The principle of operation is as follows. A significant change in the behavior of the plant in a given situation is characterized by the difference between the actual and desired state of the plant. At this moment, the fuzzy output system of the executive level produces a control signal. The implementation of it doesn't provide necessary indicators of quality control. In this case, the coordination level of adaptation block automatically sets the optimal settings for fuzzy executive level rules. Own fuzzy executive system is used in this case. The direct change of the rules of executive level is carried out by the rules base corrector. As usual, these rules are subject for linguistic correction, the activation of which in terms of linguistic assessment of control leads to inadequate control. Thus, at the coordination level there is a vague assessment of control and, if necessary, correction of the base of rules on the FC executive level. So, an intellectual assessment is carried out. It corrects the behavior of the control system, which is defined in the form of fuzzy rules at the executive level.

The structures of regulators of the coordination and executive levels are the simplest. In the general case, they have two fuzzy inputs – speed control error $e(kT)$ and its derivative (acceleration) $\sigma(kT)$[6]. An error signal $e(kT)$ is generated on the output of the first adder. Then its derivative $\sigma(kT)$ is calculated. Both signals after scaling are fed to the input of FC. Seven membership functions with triangular shape are used to fassify "error" and "error derivative" and for phasing "output signal" – nine functions of belonging to the triangular shape. They are shown in Fig. 13.

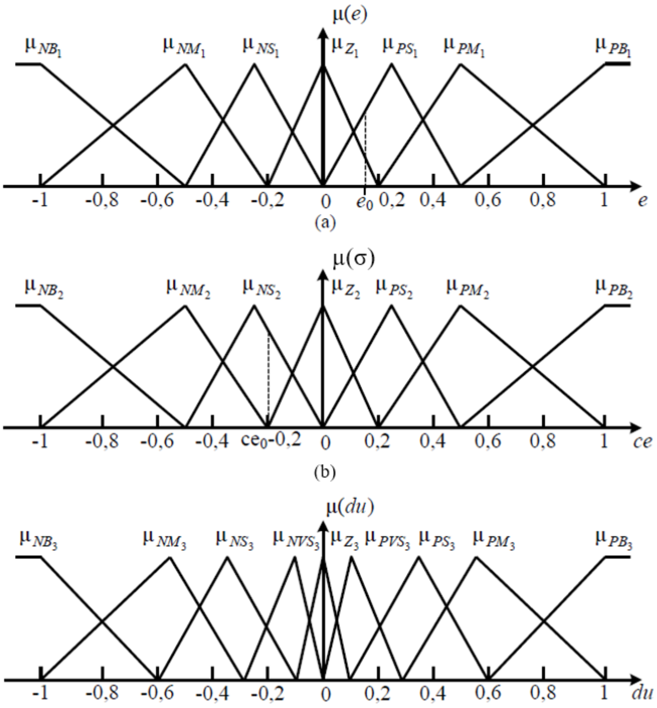

Figure 13 – Membership functions for the indistinct variables of the fuzzy control signal: (a) angular velocity error signal, (b) angular velocity error derivative signal

A fassification operation is performed when on the input of the FR error signals and its derivative occur. As a result, the active membership functions of the corresponding linguistic variables are determined. In this case, depending on the value of the input signal, from two to four active membership functions are determined. The rules database looks for rules that include a combination of active membership functions, i.e.:

$$\mu_r\left(e(kT),\sigma(kT)\right)=min\left\{\mu_i\left(e(kT)\right),\mu_i\left(\sigma(kT)\right)\right\}>\eta \qquad (1)$$

where η – is the parameter that determines the "roughness" of the search operation.

In this case, the value of the offset of the membership functions for the output signal FC in advance is calculated in the AB. For active rules, the membership functions of the output signal FC are shifted. The coordinates of the centers $c_j(kT)$ of the membership functions of the output signal at time *kT* are calculated in accordance with the following expression:

$$c_j(kT)=c_j(kT-T)+\psi b_u(kT), \qquad (2)$$

where $c_j(kT-T)$ – the centers of gravity of the membership functions of the active state on the previous cycle; ψ – change value modifier.

Next, the standard Mamdani fuzzy inference algorithm continues to be executed. This completes the rule base (at the beginning of the algorithms, the rule base is empty) and the position of the membership function of the FC signal in the normal operation mode of the plant is determined.

Formation of the output signal of FC is carried out based on the rules given in Table 2.

Table 2 – Base of FC rules

$e(kT)$ $\sigma(kT)$	NB_1	NM_1	NS_1	Z_1	PS_1	PM_1	PB_1
NB_2	NB_3	NB_3	NB_3	NM_3	NS_3	NVS_3	Z_3
NM_2	NB_3	NB_3	NM_3	NS_3	NVS_3	Z_3	PVS_3
NS_2	NB_3	NM_3	NS_3	NVS_3	Z_3	PVS_3	PS_3
Z_2	NM_3	NS_3	NVS_3	Z_3	PVS_3	PS_3	NM_3
PS_2	NS_3	NVS_3	Z_3	PVS_3	PS_3	NM_3	NB_3
PM_2	NVS_3	Z_3	PVS_3	PS_3	NM_3	NB_3	NB_3
PB_2	Z_3	PVS_3	PS_3	NM_3	NB_3	NB_3	NB_3

The block diagram shown in Fig. 9 acts as a reference model. The parameters of this model are known. This is due to the fact that the system has the desired appearance of transients.

In fig. 14 shows the transients by speed and torque. Speed overshoots are almost non-existent and adjustment time has decreased. The transition process by the torque shows that the engine no longer goes into generator mode. The adjustment time also decreased, but the fluctuations remained. This is due to the fact that the wheel is affected by the chassis from the side of the rack, on which there are damping devices. They affect the dynamics of the wheel at the time of move.

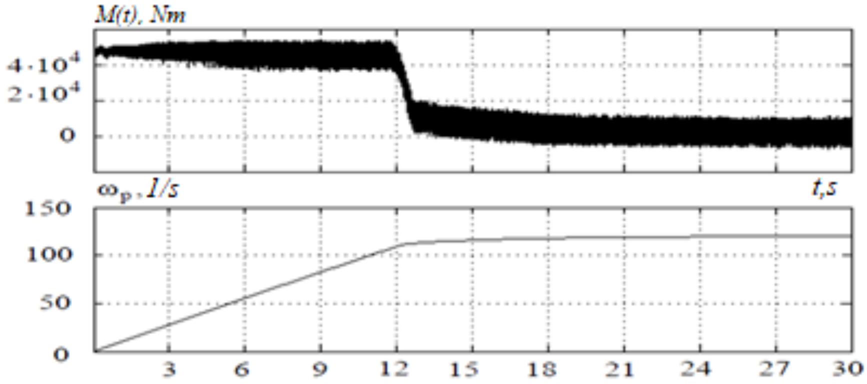

Fig. 14 – Transients by speed and torque

Conclusions:

1.Testing of the model of the traction electric drive on the basis of vector control of SDPM showed that such electric drive has excellent quality indicators in transient processes. This explains advantage of use it as an electric steering system.

2. The developed simulation model of the aircraft steering system has proven its effectiveness as a substitute for traditional methods of aircraft control.

3. Proposed adaptive fuzzy controller provides high quality control under various influences and variable EMS parameters. The robust properties of the control system allow to use the controller for objects with an undefined model. This is achieved due to the fact that the method of operation of the controller provides a simple and reasonable adjustment of its parameters.

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МОДЕЛЮВАННЯ СИСТЕМИ КЕРУВАННЯ ТЯГОВИМ ЕЛЕКТРОПРИВОДОМ РУЛІННЯ ЛІТАКА З АДАПТИВНИМ НЕЧІТКИМ РЕГУЛЯТОРОМ

Протягом останніх двох десятиліть продовжують домінувати ініціативи щодо енергооптимізації літаків. Комерційний авіаційний бізнес все частіше використовує системи екологічного контролю та електричне управління за допомогою шин змінного та постійного струму. Однією з тенденцій розвитку систем управління літаками є заміна гідравлічних та пневматичних систем на електричні. Аерокосмічна промисловість та авіакомпанії зацікавлені виконувати операції руління без використання головних двигунів. Цей спосіб експлуатації дозволяє економити паливо, зменшувати зношення гальм, виключає буксирування та досягає зменшення забруднення навколишнього середовища. Надалі необхідно реалізувати електричне рульове управління за допомогою тягового приводу на базі синхронного двигуна з постійними магнітами). Це дослідження представляє високоефективну систему електричного рульового управління як сучасне рішення для поліпшення наземних операцій сучасних літаків, що працюють від основних двигунів. Система була досліджена з використанням рульових профілів зльоту та посадки. Результати моделювання динамічних процесів електромеханічної системи, що містить пружні ланки, в умовах параметричних збурень підтвердили стійку стабілізацію показників якості динамічного управління на основі законів нечіткої логіки.

Ключові слова: система керування, тяговий електропривод, руління літаком, нечіткий регулятор.

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