TRANSPORT SYSTEMS

UDC 681.511.4(045)

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ANALYSIS OF UNMANNED AERIAL VEHICLE CONTROL SYSTEM

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Abstract. *The principles of construction and comparative evaluation of control systems unmanned aerial vehicle is considered.*

Keywords: control system; command forming device; operator; line transmission command; stiffness, damping.

Introduction

Interest that is shown to the unmanned aerial vehicles (UAV), is completely obvious. Different industries of application pay attention them. Thus the basic task of developers of UAV is providing of quality of controlling an object.

Unmanned aerial vehicles controlling provides an operator (Op) with the help of special devices of automation (fig. 1).

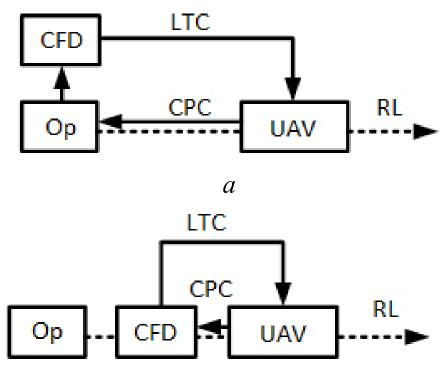


Fig. 1. Unmanned aerial vehicles control systems:
a – manual; *b* – semi-automatic

Basic functional element of control systems is a commands forming device (CFD). As line transmission commands (LTC) can be used the leading communication lines, radio contact, directed laser radiation. Spatial route line (RL) direction of UAV is set by an operator. Channel of position control (CPC) of UAV in relation to the route line (RL), is optical, as a rule.

Control systems, based on their level of automation can be manual or semi-automatic. In the manual system the operator is located in the contour of UAV controlling. He assesses the UAV position at the route and through the CFD forms controlling commands. The last is passed for LTC on the unmanned aerial vehicle, providing its flight on the set trajectory.

In semi-automatic systems (fig.1, *b*) an operator is excluded from the control circuit. Its main task is forming of the route line (RL). And UAV controlling takes place automatically. Thus CFD controls position of UAV enroute and forms controlling commands.

That or other type of control system is used depending on tasks, fixed on UAV. Researching of basic indexes of control systems quality allows to hold their comparative estimation and produce recommendations, directed on UAV effective application.

Solution of problem

Structure schemes of semi-automatic control systems are presented in fig. 2. Unmanned aerial vehicles as control object is described by the transfer function $W_0(s) = \dfrac{k_0}{T_0 s + 1}$. An input signal is the angle ψ_g of the reference track (course angle), which sets by the operator, output – the angle ψ_o of UAV course. In general, at the control object is influenced by the disturbance moment $M_{y\Sigma}$.

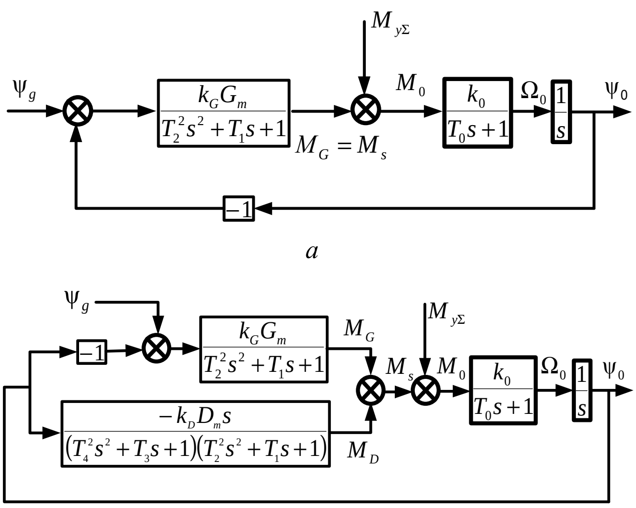


Fig. 2. Block diagrams of semi-automatic control system:
a – single-circuit; *b* – double-circuit

The analysis of variant implementation of the control systems shows that they are the position systems of automatic control on the UAV inconsistency angle in relation to the direction set by operator. Thus the moment M_s of UAV stabilizing can be formed both on one and on two channels.

At single-circuit system implementation (fig. 2, *a*) a stabilizing moment is formed on the sensor channel of angular rejection of management object.

$$\bar{M}_s = \bar{M}_G \equiv k_G G_m,$$

where G_m – structural inflexibility of control systems, which depends on the constant transmission coefficients of elements input into it; $0 \le k_G \le 1$ – coefficient of inflexibility regulation.

At the double-circuit variant of stabilizing moment forming, it provides sensor channels of an angular rejection and speed sensor of an angular rejection of management object

$$\bar{M}_s = \bar{M}_G + \bar{M}_D \equiv k_G G_m + k_D D_m,$$

where D_m – structural control system damping; $0 \le k_D \le 1$ – damping regulation coefficient.

The system's block diagram with separated channels of moment forming is resulted on fig. 2, *b*. The area of control system stability [1; 2] in parameters $k_D D_m$ – $k_G G_m$ has the form, shown on fig. 3. It limits the possible values of the stiffness and damping of the system.

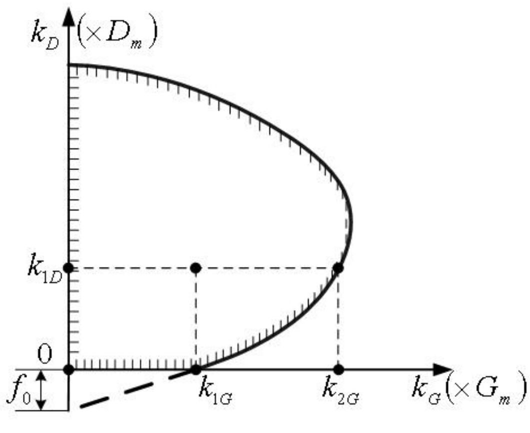
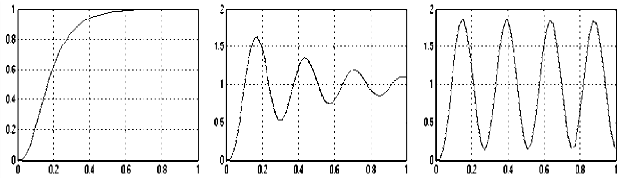


Fig. 3. Area of control system stability

As in the single-circuit systems $k_D D_m = 0$, they are stable only at the small values of stiffness $(0 - k_{1G} G_m)$, which correspond to a damping the UAV by friction f_0. Thus the single-circuit systems can provide necessary quality of management completely. The dynamics change of single-circuit system surge characteristic at the inflexibility values increasing $k_G G_m = 0,01G_m;\ 0,05G_m;\ 0,068G_m$ is presented on fig. 4.

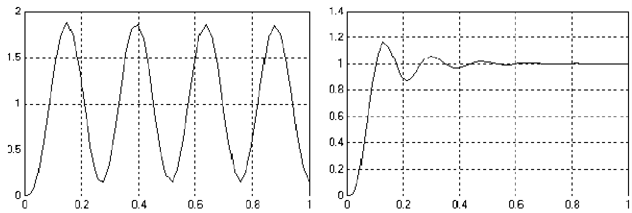


a *b* *c*

Fig. 4. Surge characteristics of single-circuit control system: *a* – $k_G G_m = 0,01G_m$; *b* – $k_G G_m = 0,05G_m$; *c* – $k_G G_m = 0,068G_m$

Presence of the speed sensor of the angular management object rejection at the dual-channel system extends the area of it's stability, allowing to adjust the system on greater stiffness and as a result – to provide the higher exactness of UAV stabilizing. From the fig. 4 we can see that at the damping that is equal to $k_{1D} D_m$, maximum stiffness of the double-circuit system as compared to the single-circuit can be increased from $k_{1G} G_m$ to $k_{2G} G_m$.

Fig. 5 illustrates the change of surge process at introduction in the complement of the control system of the speed sensor circuit – the system which is on the firmness border at $k_D D_m = 0$ and $k_G G_m = 0,068G_m$, becomes serviceable if damping $k_D D_m = 0,06D_m$ is provided and former stiffness – $k_G G_m = 0,068G_m$.



a *b*

Fig. 5. Surge characteristic of single-circuit (*a*) and double-circuit (*b*) systems: *a* – $0D_m \leftrightarrow 0,068G_m$; *b* – $0,06D_m \leftrightarrow 0,068G_m$

The block diagram of hand control system is presented on the fig. 6. An operator in the UAV control circuit is presented in accordance with [3] by a transfer function

$$W_{\text{op}}(s) = \frac{e^{-\tau s}}{\left(T_{\text{op}} s + 1\right)^2}.$$

Sensorimotor of an operator determines it's time constant T_{op} and delay τ of the executive reaction.

Including of the operator in the UAV control circuit definitely influences on the system dynamics.

Transitional descriptions of the single-circuit semi-automatic and hand controlled systems at the equality of their stiffness's $0,03G_m$ and mean values of operator parameters presented on the fig. 7 *a*, *b*. Comparison of descriptions is not obviously folded in behalf of the hand controlled system. It costs to search a principal reason in the selected parameters of an operator.

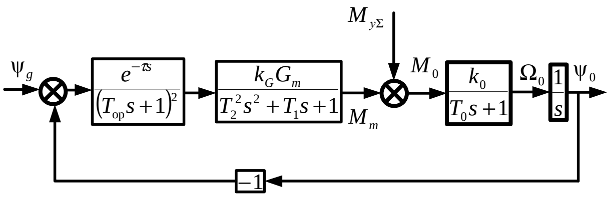
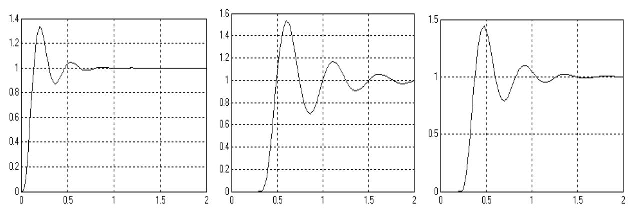


Fig. 6. Structure scheme of the hand controlled system

It is necessary to take into account that parameters of different operators can substantially differ from each other. They can change in the same operator, coming from a volume of executable work and its tension. Many of them are depends on the fatigueability of concrete individuals, their capabilities, trainings ...



a *b* *c*

Fig. 7. Surge characteristics of control systems:
a – of single-circuit semi-automatic; *b* – of manually-controlled and operator mean values; *c* – of hand-controlled and operator parameters above the average

From positions of the automatic control theory, a man is a plastic enough dynamic link. During studies and trainings he adapts well both to the UAV control systems and to the terms, in which management is carried out. The main consists in that the got knowledges and skills were constantly supported on a necessity levels and perfected constantly.

On the fig. 7, *c* is showed the surge characteristic of the single-circuit hand control system at the operator parameters that are higher than average. It is not difficult to notice that the system dynamics became better notedly. At the high preparation level of an operators, quality of hand UAV control systems can be maximally close to the semi-automatic systems quality.

Conclusions

Thus, going out from the tasks, fixed on UAV:

– semi-automatic and hand control system can be realized in practice;

– introduction in the complement of the controlling system of the adjusting channel for speeds of control object rejection is extended by the area of its stability, allowing by the same to provide higher exactness of controlling;

– at the estimation of UAV control system quality, their accordance's to the requirements it is necessary to take into account not only the perfection of the systems construction, but ability and skills of an operator, level of his preparation and qualification.

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Received 30 September 2013

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О. К. Аблесімов, К. В. Сарапіна. Аналіз систем керування безпілотних літальних апаратів

Викладено принципи побудови і порівняльна оцінка системи керування безпілотних літальних апаратів.

Ключові слова: система керування, оператор, пристрій формування команд, лінія передачі команд, жорсткість, демпфірування.

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Освіта: Національний авіаційний університет, Київ, Україна (2012).
Напрямок наукової діяльності: автоматичні системи керування.
Кількість публікацій: 2.
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А. К. Аблесимов, Е. В. Сарапина. Анализ систем управления беспилотных летательных аппаратов

Изложены принципы построения и сравнительная оценка системы управления беспилотных летательных аппаратов.

Ключевые слова: система управления, оператор, устройство формирования команд, линия передачи команд, жесткость, демпфирование.

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