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DETERMINATION OF COMPLEX AIRCRAFT - OPERATOR CONTROL SYSTEM PROPERTIES

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Abstract. The automatization of particularly fast maneuvering aircraft has greatly reduced the sphere of man's scope by freeing him from routine operator work and moving it to the highest hierarchical level of the system. This forces aerospace manufacturers and users to address questions of a kind in a new way: how to design an ergatic system (ergatic system), how to optimize the coordination or human operator's entry into the "machine part", that has a distinctive feature of artificial intelligence. In this article, the properties of the ergatic system are investigated in order to determine the stability of the system in the longitudinal steady-state equilibrium flight mode at 22 965 ft, Mach 0.8, VTAS = 250 m/s. The Control System Toolbox, which is focused on solving tasks related to the analysis and synthesis of linear time - invariant dynamic systems, was used to solve the example. The basic prerequisite for the use of individual toolbox modules is knowledge mathematical models of controlled processes described in the state space, by means of transfer functions in s - area, z - area, time area, in the form of poles, zeros and amplification.

Keywords: ergatic system; longitudinal flight mode stability; time - invariant dynamic systems

1. INTRODUCTION

Computer modelling of aviation technology is a method that extends the possibilities and improves the practical training of aviation professionals with a reflection in the safety of air transport [1]. Nowadays, computer models represent the intelligent effects of human-machine-environment connections that unify the concept of an ergatic complex [2]. The robust control theory of dynamic systems elaborates methods for analysis of robust properties of real objects and proposes controllers that will ensure robustness of the feedback system. A peculiarity of this theory of dynamic systems control is that modelling, object property analysis, and controller synthesis are accomplished by incomplete and inaccurate mathematical description of the controlled process [3]. The change of parameters depends on the operating conditions as well as on the change of parameters, therefore the considered system in a more complex concept cannot be clearly described by a single mathematical model, but an extended model is necessary [1], [4]. The technical results must meet the requirements for ergatic system as well as the requirements to eliminate negative impacts on the environment and public health, which are given increased attention and publicity, such as the risk assessment [2] or the overall quantitative assessment of environmental projects in the aviation sector [5], etc.

2. CHAPTER EXAMINATION OF ERGATIC SYSTEM STABILITY

The Control System Toolbox, which is focused on solving tasks related to the analysis and synthesis of linear time-invariant dynamic systems [6], [7], [8], was used to solve the example. The basic prerequisite for the use of individual Toolbox modules is knowledge of mathematical models of controlled processes described in the state space, using transfer functions in s - area, z - area, time area, in the form of poles and zeros and gain. Control for stability analysis we use frequency characteristics in a complex plane and in logarithmic coordinates with the possibility of obtaining reserve values in phase and amplitude [9], [10], [11]. To analyse the stability and quality of control circuits, we can use the method of geometric roots location, which provides a detailed view of the position of roots in relation to the gain value.

Dynamics of the examined ergatic complex is determined by vector equations:

$$\begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) + Bp(w), \\ y(t) &= Cx(t) + Gu(t). \end{aligned} \tag{1}$$

Vectors states $x = (v, \alpha, \dot{\theta}, \theta)$ flight speed change, angle of attack, derivation of theta angle, change of theta angle. Vector control $u(t) = [\delta_e, \delta_f]^T$ (elevator deviation, flaps deviation). Scalar quantity that is entered by the operator (pilot): W. The stabilization system is a compensation device described by vector equations:

$$\begin{aligned} u(t) &= k_1 x(t) + k_2 z(t) + k_3 w(t), \\ \dot{z}(t) &= k_4 z(t) + k_5 x(t) + k_6 w(t), \end{aligned} \tag{2}$$

Entered values of deviations from equilibrium state in matrix form are:

$$A = \begin{bmatrix} -0.013 & -0.346 & 0 & -2.349 \\ -0.001 & -0.932 & 0.994 & 0 \\ 0.0004 & 5.887 & 0.927 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{3}$$

$$\mathrm{B} = \begin{bmatrix} -1.347 & -0.568 \\ -0.126 & 0.151 \\ -17.89 & -4.473 \\ 0 & 0 \end{bmatrix} \tag{4}$$

$$B_p = B \cdot \begin{bmatrix} -1 \\ -0.25 \end{bmatrix} \tag{5}$$

The equation system (2) includes six K-matrices of gain coefficients. E.g. the matrix K_1 contains the measured values:

$$K_1 = \begin{bmatrix} 0 & 0.048 & 0.258 & 0.121 \\ 0 & -0.002 & 0.045 & 0.035 \end{bmatrix} \tag{6}$$

If, $K_2 = K_3 = K_4 = K_5 = K_5 = 0$the matrix of the constants will be $C = K_1 = C_1$, then:

$$C_1 = \begin{bmatrix} 0 & 0.048 & 0.258 & 0.121 \\ 0 & -0.002 & 0.045 & 0.035 \end{bmatrix} \tag{7}$$

The matrix $\boldsymbol{G}$ represents the direct input of the operator - pilot to the control of the elevator and flaps. The following applies to these inputs:

$$\mathrm{G} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \tag{8}$$

3. RESULTS OF ERGATIC SYSTEM STABILITY

Vector equations (2) are the MIMO (Multiple Input Multiple Output) model that we create in the MATLAB environment. The Bp matrix does not enter into the instability compensation of the ergatic complex. Its value position has an impact on operator-pilot input.

Let's name the state variables of vector x:

```
states={'DV' 'Dalfa' 'DER.theta' 'Dtheta'};
inputs={'Dve' 'Dvf'};
```

```
outputs={'DER.theta' 'Dtheta'};
sys_mimo=ss(A,B,C1,G,'statename',states,'inputname',inputs,'outputname',o
utputs),
```

Find the geometric place of the roots locus (RL), perform the analysis:

```
axis(gca,'normal'),h =
pzplot(sys_mimo),setoptions(h,'FreqUnits','rad/sec','Grid','off'),
```

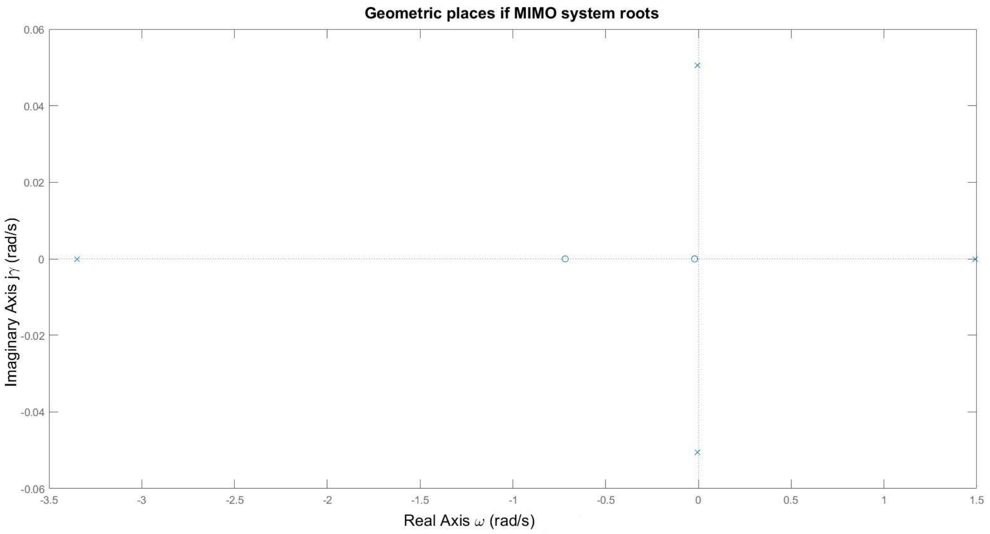

Figure 11 Geometric places of MIMO system roots

The model is unstable, as evidenced by the impulse plot, which can be seen in Fig. 2

```
impulseplot(sys_mimo,20),
tf(sys_mimo)
```

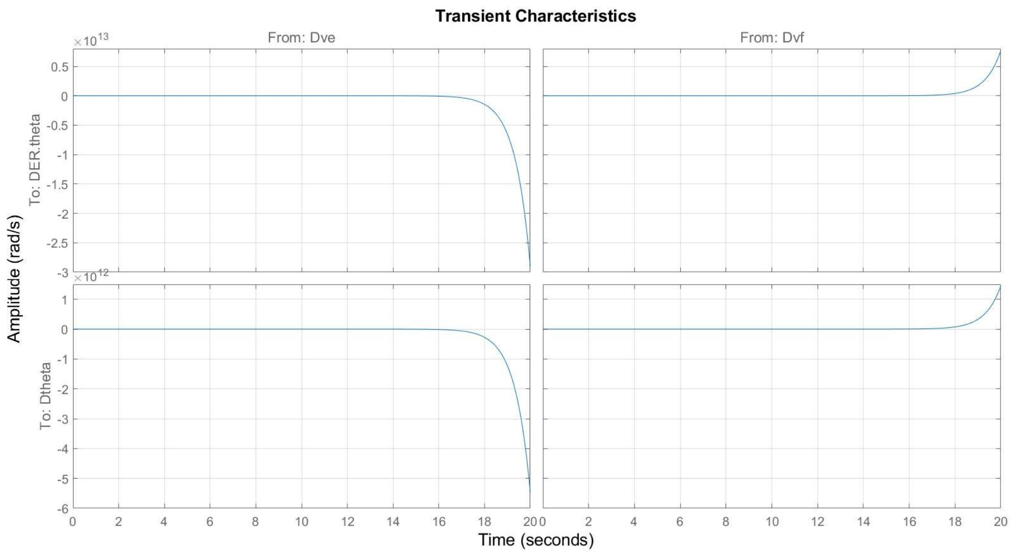

Figure 22 Transient characteristics of an unstable MIMO ergatic system

Select input-output 'ss_ MIMO' for analysis:

Input (Dve) – output (DER.theta), which represents 'ssSISO'.
Let's mark the system: Dve-DER. Theta with symbol 'sys11'.

Then:

```
sys11=sys_mimo(,DER.theta',‘Dve‘),h=bodeplot(sys11),setoptions(h,
,FreqUnits‘,‘rad/sec‘,‘MagUnits‘,‘dB‘,‘PhaseUnits‘,‘deg‘),
```

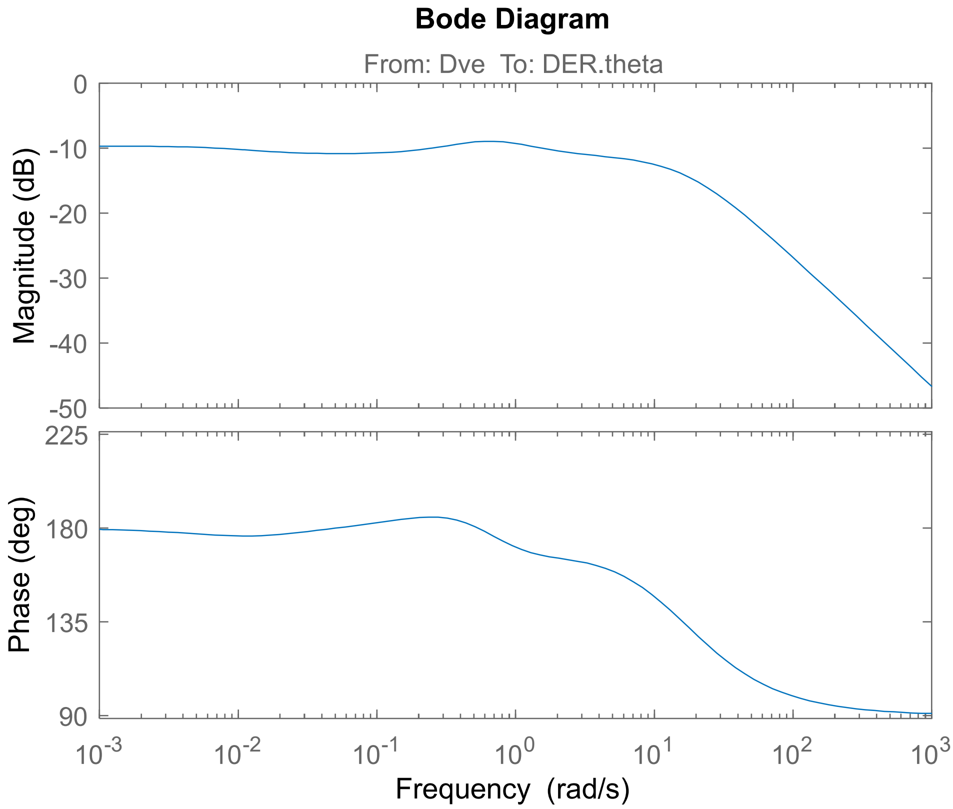

Figure 33 Amplitude and phase frequency characteristics of analysed SISO system

The transformation of ss11 to the transfer function is:

```
tf(sys11)
```

transfer function from input " Dve " to output.

$$DER.theta: \frac{-4.622s^3 - 7.577s^2 - 2.201s - 0.02777}{s^4 + 1.872s^3 - 4.964s^2 - 0.06408s - 0.01295} \quad (9)$$

$$Dtheta: \frac{-0.8048s^3 - 1.385s^2 - 0.6268s - 0.007362}{s^4 + 1.872s^3 - 4.964s^2 - 0.06408s - 0.01295} \quad (10)$$

Transfer function from input "Dlf" to output

$$DER.theta: \frac{1.161s^3 + 2.081s^2 + 0.6392s + 0.008656}{s^4 + 1.872s^3 - 4.964s^2 - 0.06408s - 0.01295} \quad (11)$$

$$Dtheta: \frac{0.201s^3 + 0.3776s^2 + 0.182s + 0.002335}{s^4 + 1.872s^3 - 4.964s^2 - 0.06408s - 0.01295} \quad (12)$$

The unstable model expressed by said transfer function requires a compensation circuit whose design is the subject of synthesis [2].

Synthesis of the compensation circuit using the geometric location of the roots.

We will perform the compensation circuit synthesis using the RL method:
To gain the process, we introduce the following:

```
h11=sys11,
R = rlocusplot(h11),setoptions(R,‘FreqUnits‘,‘rad/sec‘),
```

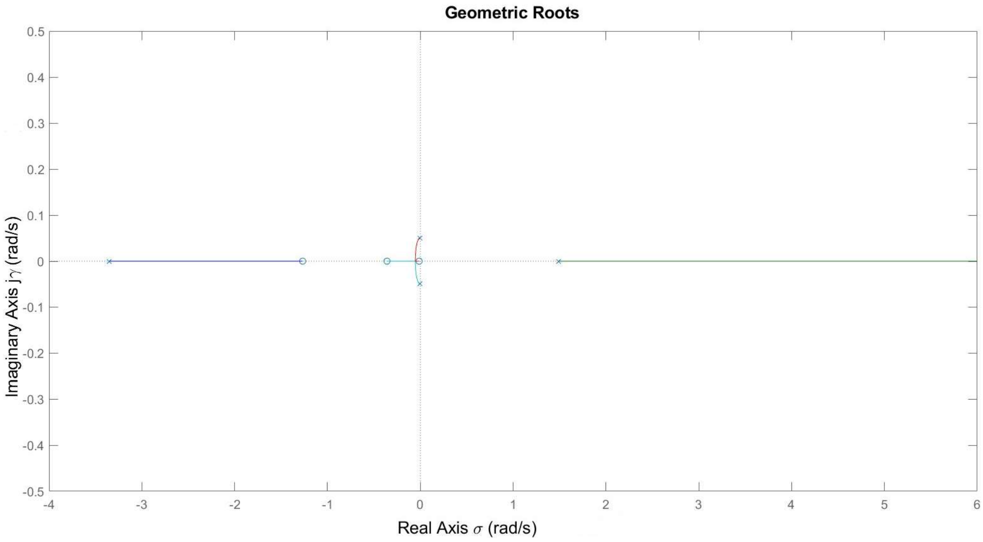

Figure 44 Geometric roots of compensated system roots

The distribution of zeros and poles in Figure 4 corresponds to positive gain values ‘k’. For negative ‘k’ we get the area.

```
R = rlocusplot(h11),setoptions(R,‘FreqUnits‘,‘rad/sec‘),
R = rlocusplot(-h11),setoptions(R,‘FreqUnits‘,‘rad/sec‘),
```

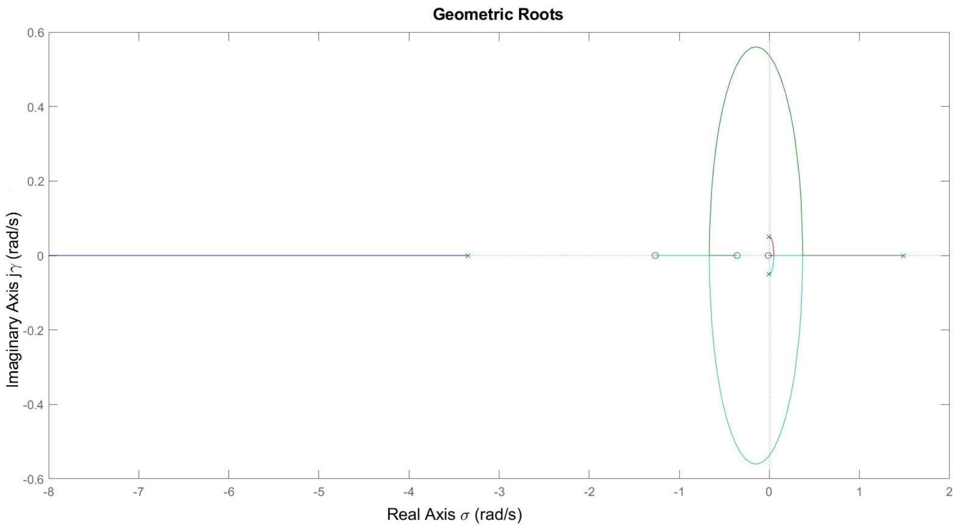

Figure 55 Geometric roots for the selected feedback gain value

The frequency requirement, the over-regulation value and the position of the zeros and poles decided:

```
k=-3.51,
```

The RL method accepts the indicated gain in the internal feedback loop.
Its transmission function under the designation Hsv has the form:

```
Hsv=tf(-3.51,[0,1]),
```

The transfer function of the direct – unstable branch is:

```
Hpv=h11,
```

Aircraft model instability compensator – non-ergatic part works in antiparallel circuit.

```
Cloop=feedback(Hpv,Hsv),
tf(cloop)
```

Calculated transmission function of monitored circuit: DERtheta/Dve, indicates stability of compensator circuit. The compensator belongs to the class of linear time invariant systems (LTI). The transient characteristic is determined by:

```
sys_lti(:,:,1,1)=(cloop),
step(sys_lti),
```

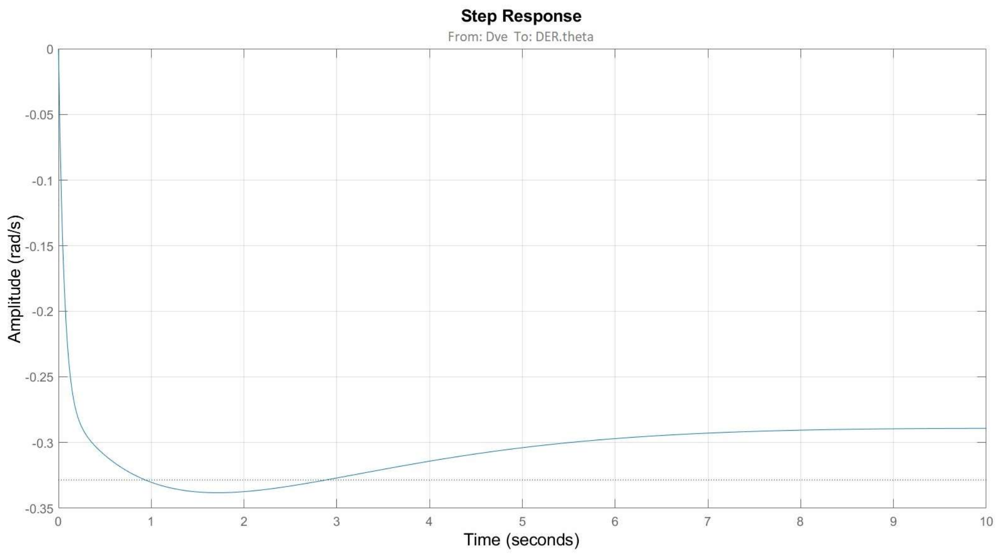

Figure 66 Transient characteristic of analysed system with designed compensator

Impulse characteristic:

```
impulseplot(cloop,5),
```

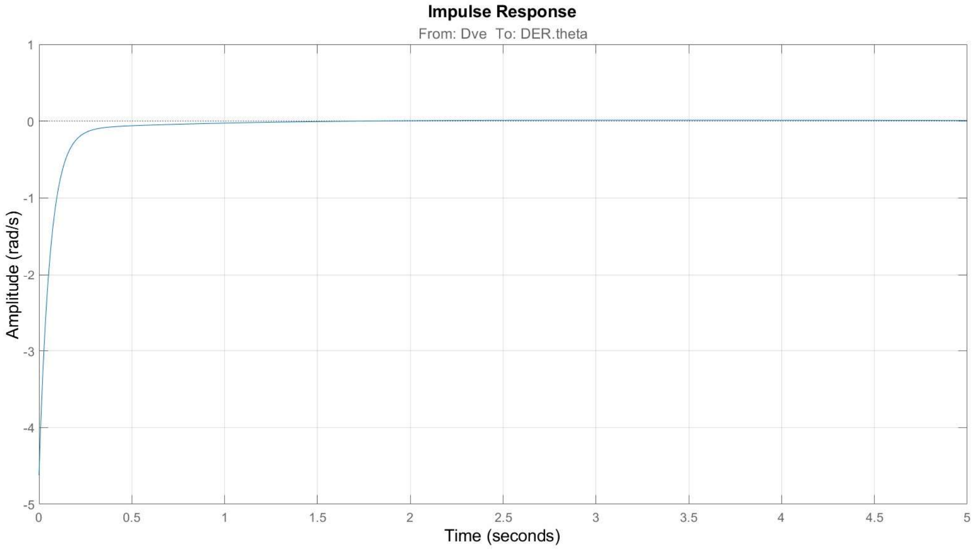

Figure 77 **Impulse characteristic of analysed system with designed compensator**

Root Locus:

```
R = rlocusplot(cloop),setoptions(R,'FreqUnits','rad/sec'),
bode(cloop),
```

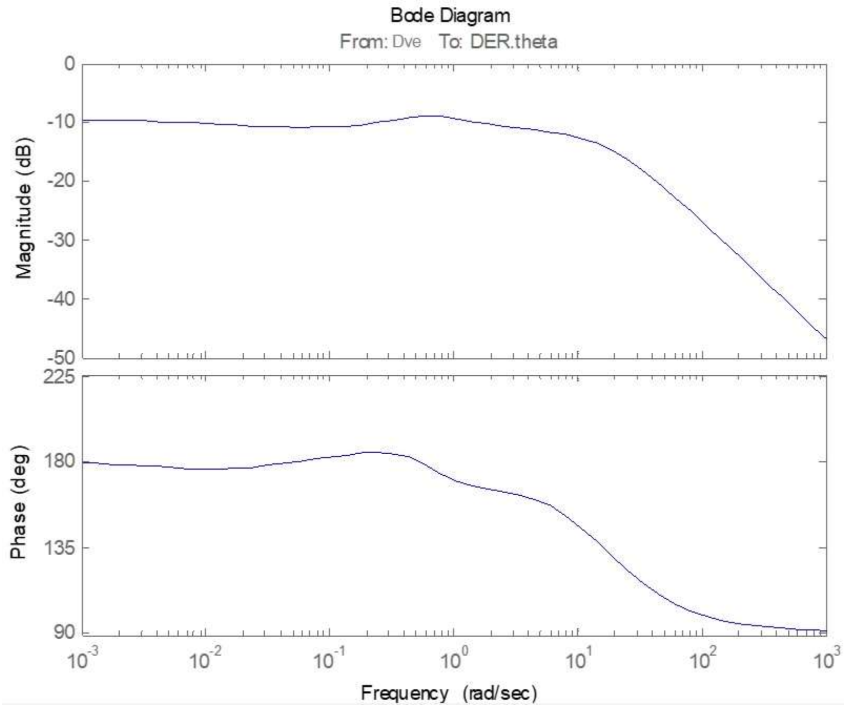

Figure 88 **Amplitude and phase frequency response with designed compensator**

4. CONCLUSION

The added designed compensator stabilizes the model when gain in a narrow stability band, such a feature of the compensator can be used in an ergatic system for training and education of operators. When monitoring flight safety, the compensator requires the scope of the permitted changes and their instrumental security. Analytical - synthetic considerations can be associated with the principles of the function of the ergatic complex. Another procedure is to solve the compensator: Dve - Dtheta (sys12), Dkf - DER.theta, Dkf – Dtheta (sys22), It is also possible to design circuits of ergatic complex control by analytical - synthetic method and to determine limit situations of ergatic complex and their solution by artificial intelligence methods.

The used method can be applied in the synthesis of compensators with matrices K2 to K6 and solve the lateral movement of the ergatic system using the GMK method. Subsequently, it is possible to determine the limitations of the spatial movement of the ergatic complex and instrumentally ensure control limits, as the input of the circuit is connected to the operator-pilot signals 'w' through the matrix Bp.

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