The Vehicle Controlling Near the Screening Surface Using Thrust Vector Deflection of the Electric Motor with Gimbal Mounted Propeller

Kravets V.V. [1, a], Kravets Vl.V.[2, b], Artemchuk V.V.[2]

1− State Higher Educational Institution "National Mining University", Dnipro, Ukraine

2− National University of Railway Transport, Dnipro, Ukraine

a – prof.w.kravets@gmail.com

b – vladkravetsphd@gmail.com

DOI **10.2412/mmse.2.35.544** provided by Seo4U.link

Keywords: gimbal system, rotational scheme, quaternionic matrices, Rodrigues-Hamilton parameters, components of control forces and moments.

ABSTRACT. The controlled spatial motion of the combined vehicle near the screening surface is considered. A propeller motor in a gimbal mount forms control forces and moments. The gimbal mount scheme can be defined on a finite set of successive three independent turns with recurrence, which is represented by 96 variants. The constructive scheme of the gimbal mount of propeller electric motor is proposed, which provides control of combined vehicle in the three main modes: Lifting force (helicopter scheme); Traction mode (aircraft scheme); Lateral traction (course control). The rotative axis of the propeller is combined in coincidence with rotor axis of electric motor determining the first turning of the gimbal mount. The electric motor's stator is located on the inner ring of the gimbal and its rotation axis determines the second finite turn. The turning axis of the outer race of the gimbal relatively the case of the combined vehicle defines the third finite turning movement. This constructive solving of the gimbal mount provides the combined control of thrust vector in wide range of finite turning angles. Basis of movable Cartesian coordinate system is coincides with the rotation axes intersection point. For the entered reference systems and the accepted sequence of finite independent turning movements matrixes of the forward and inverse transform of coordinates in the form of quaternion matrixes are formed. In the form of quaternion matrices, depending on the angle of the thrust vector and the arrangement of the gimbal mount, the driving forces and moments in the reference frame that is associated with the vehicle are determined.

Introduction. The movement of the aircraft in space is defined by the control forces and moments formed by the control system [1]. Traditionally, the magnitude of control forces is determined by small deflection of the thrust vector relative to the aircraft's center of mass. On rarely - with applying a small deflection of the aircraft center of mass relative to the thrust vector, by displacing the carried mass [2]. In both methods of control, the gimbal system has been widely used [3]. Different sequences of three independent turning in space form a finite set consisting of 96 variants [4].

In this study, among these options, the turning scheme of gimbal motion for propeller electric motor is selected, which provides control of the thrust vector over a wide range of angles.

Formulation of the problem. We regard a propeller electric motor, the thrust of which is directed along the axis of rotation of the electric motor rotor. It is necessary to provide the control of the combined vehicle's movement by applying the turning of the thrust vector in the required range of angles, which providing a combination of the basic propeller motor modes of action:

- Lifting force mode;
- Traction mode;
- Lateral traction.

Scheme of turns. The first infinite turn in the positive direction by angle α is determined by the axis of the propeller's rotation together with the electric motor rotor in the gimbal and is denoted by [5]:

$$\bar{e}_{y1},\ +\alpha. \tag{1}$$

The second finite turn in the positive direction by the angle β is determined by the axis of rotation of the inner gimbal, which connected to the stator of electric motor and is denoted as:

$$\bar{e}_{y2},\ +\beta. \tag{2}$$

The third finite turn with a reiteration in positive direction $\bar{e}_{y1}$ by the angle α is determined by the axis of rotation of the outer gimbal attitude to vehicle's body and is denoted as follows:

$$\bar{e}_{y1},\ +\alpha. \tag{3}$$

Here, with a gimbal mount, the basis of movable Cartesian coordinate system $\bar{e}_{y1},\ \bar{e}_{y2},\ \bar{e}_{y3}$ is associated, the starting of which is combined with the point of intersection of the turning axes.

The proposed system of three independent turning with reiteration composed the third variant of a possible set of 96 rotations with reiteration [4]. This system is designated as: $S_3(+\alpha,+\beta,+\alpha)$, where the first turn corresponds to the angle of rotation of the propeller or rotor of the electric motor, i.e. $\varphi \equiv +\alpha$; Second turn - pitch angle, i.e. $v \equiv +\beta$; Third turn - course's angle, i.e. $\psi \equiv +\alpha$. The general view of the gimbal with the described sequence of turns is shown in Fig. 1.

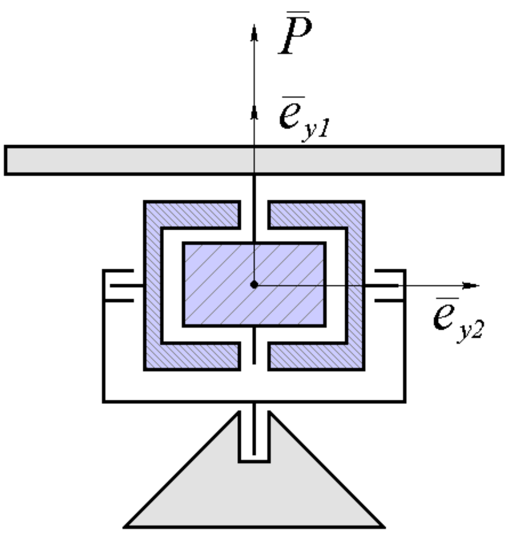

Fig. 1. Constructive scheme of the thrust vector turns ($\bar{P}$) for propeller electric motor in the gimbal

The intervals of changing the angles of turn are as follows:

$$\begin{aligned} &1. \quad 0 \le \varphi < \infty; \\ &2. \ -90^\circ \le \nu \le 90^\circ; \\ &3. \ -90^\circ \le \psi \le 90^\circ. \end{aligned} \tag{4}$$

The main modes of control action of the propeller’s thrust vector for a combined vehicle in flight mode are provided by the second and third finite turn of the gimbal mount with the angles’ values:

Lifting force (helicopter scheme):

$$\nu = 0, \quad \psi = 0; \tag{5}$$

1. Traction mode (aircraft scheme):
2.

$$\nu = \pm 90^\circ, \qquad \psi = 0; \tag{6}$$

3. Lateral traction mode (course control):
4.

$$\nu = \pm 90^\circ, \qquad \psi = \pm 90^\circ. \tag{7}$$

Rodrigues-Hamilton parameters. Two consecutive turns of the Cartesian coordinate system mobile basis associated with the gimbal mount, regarding the basis of the reference frame fixed on the vehicle, are characterized by the following set of Rodrigues-Hamilton parameters [5]:

$$\begin{aligned} &b_0 = \cos\frac{\nu}{2}, \quad b_1 = 0, \quad b_2 = \sin\frac{\nu}{2}, \quad b_3 = 0, \\ &c_0 = \cos\frac{\psi}{2}, \quad c_1 = \sin\frac{\psi}{2}, \quad c_2 = 0, \quad c_3 = 0. \end{aligned} \tag{8}$$

Quaternionic matrices. According to these Rodrigues-Hamilton parameters, two sets of quaternionic matrices of the form [6] are formed:

$$\begin{aligned} &B, \quad {}^tB, \quad B^t, \quad {}^tB^t, \\ &C, \quad {}^tC, \quad C^t, \quad {}^tC^t \end{aligned} \tag{9}$$

or in expanded form:

$$B = \begin{Vmatrix} \cos\frac{v}{2} & 0 & -\sin\frac{v}{2} & 0 \\ 0 & \cos\frac{v}{2} & 0 & -\sin\frac{v}{2} \\ -\sin\frac{v}{2} & 0 & \cos\frac{v}{2} & 0 \\ 0 & -\sin\frac{v}{2} & 0 & \cos\frac{v}{2} \end{Vmatrix}, \; C = \begin{Vmatrix} \cos\frac{\psi}{2} & -\sin\frac{\psi}{2} & 0 & 0 \\ -\sin\frac{\psi}{2} & \cos\frac{\psi}{2} & 0 & 0 \\ 0 & 0 & \cos\frac{\psi}{2} & -\sin\frac{\psi}{2} \\ 0 & 0 & -\sin\frac{\psi}{2} & \cos\frac{\psi}{2} \end{Vmatrix}. \quad (10)$$

Then, for the formation of quaternionic matrices, the operation of external – ${}^tB$, ${}^tC$, internal – B^t, C^t and complete – ${}^tB^t$ ${}^tC^t$ transposition is used [6]. The quaternionic matrices of the resulting turn are determined in the form [5]:

$$R = B\cdot C, \qquad {}^tR = {}^tB\cdot {}^tC. \quad (11)$$

Similarly, there are matrices of the resultant turn, which are equivalent to the conjugate quaternion:

$${}^tR^t = {}^tC^t\cdot {}^tB^t, \; R^t = C^t\cdot B^t. \quad (12)$$

Tables of directing cosines. The directing cosine tables for direct and inverse transformations of the thrust vector in the reference frames associated with the gimbal system and a vehicle are determined respectively in the core of the product of two resultant matrices that are equivalent to a quaternion [4]:

$$R\cdot {}^tR \quad \text{or} \quad {}^tR\cdot R \quad (13)$$

and the conjugate quaternion

$$R^t\cdot {}^tR^t \quad \text{or} \quad {}^tR^t\cdot R^t. \quad (14)$$

Components of control forces and moments. The problems of dynamic design of the motion of a combined vehicle near the screening surface [7] are solved using a computational experiment. Here we apply a mathematical model of nonlinear dynamics in the form of Euler-Lagrange spatial motion equations and quaternion matrices [8, 9]. The components of the control forces and moments depend on the module (P) and the direction of the thrust force, which is set by the angles of the turn in the gimbal (v, ψ), the point of application of the thrust force in the gimbal system relative to the layout axes – x_1^0, x_2^0, x_3^0 . These components are defined as follows:

$$\left\| \begin{array}{c} \frac{1}{2}\left(X_0 + {}^tX_0\right) \\ \hline E \end{array} \right\| R \cdot {}^tR \cdot \left\| \begin{array}{c} 0 \\ P \\ 0 \\ 0 \end{array} \right\|, \qquad (15)$$

where E − the identity matrix (4x4);

$X_0, {}^tX_0$ − quaternionic matrix:

$$X_0 = \left\| \begin{array}{cccc} 0 & x_1^0 & x_2^0 & x_3^0 \\ -x_1^0 & 0 & -x_3^0 & x_2^0 \\ -x_2^0 & x_3^0 & 0 & -x_1^0 \\ -x_3^0 & -x_2^0 & x_1^0 & 0 \end{array} \right\|, \quad {}^tX_0 = \left\| \begin{array}{cccc} 0 & -x_1^0 & -x_2^0 & -x_3^0 \\ x_1^0 & 0 & -x_3^0 & x_2^0 \\ x_2^0 & x_3^0 & 0 & -x_1^0 \\ x_3^0 & -x_2^0 & x_1^0 & 0 \end{array} \right\|. \qquad (16)$$

Summary. A constructive scheme of the finite turns of thrust vector for propeller electric motor in the gimbal mount is proposed for motion controlling of the combined vehicle near the screening surface. The components of the control forces and moments are determined in the form of quaternionic matrices that are compiled according to the Rodrigues-Hamilton parameters, the gimbal's placement coordinates in the vehicle's layout axes, and adapt to the equations of the Euler-Lagrange spatial motion.

References

[1] Igdalov, I.M., Kuchma, L.D., Polyakov N.V., Sheptun Yu.D. Rocket as a control object (in Russian), Dnipropetrovsk, Art-Press Publ., 2004, 544 P. ISBN: 966-7985-81-4.

[2] Kravets V.V. 1978. Dynamics of solid bodies system in the context of complex control (in Russian), Applied Mechanics, Issue 7, P. 125-128.

[3] Ishlinskij, A.Yu. Orientation, gyroscopes and inertial navigation, (in Russian). Moscow, Nauka Publ., 1976, 672 P.

[4] Kravets, V., Kravets, T., Burov, O (2017). Applying Calculations of Quaternionic Matrices for Formation of the Tables of Directional Cosines. Mechanics, Materials Science & Engineering, Vol. 10. In press.

[5] Victor Kravets, Tamila Kravets, Olexiy Burov. Application of Quaternionic Matrices for Finite Turns' Sequence Representation in Space. MMSE Journal, Vol. 9. 2017. P. 408-422. DOI http://seo4u.link/10.2412/mmse.17.56.743.

[6] Kravets, V., Kravets, T., Burov, O. Monomial (1, 0, -1)-matrices-(4x4). Part 1. Application to the transfer in space. LAP, Lambert Academic Publishing, Omni Scriptum GmbH&Co. KG., 2016, 137 P. ISBN: 978-3-330-01784-9.

[7] Kravets V.V., Kravets Vl.V., Fedoriachenko S.A. (2016) On Application of the Ground Effect For Highspeed Surface Vehicles MMSE Journal, Vol. 4, P. 82-87. Open access: www.mmse.xyz, DOI: 10.13140/RG.2.1.1034.5365.

[8] Kravets V.V., Bass K.M., Kravets T.V., Tokar L.A. (2015) Dynamic design of ground transport with the help of computational experiment, MMSE Journal, Vol.1, 105-111. ISSN 2412-5954, DOI 10.13140/RG.2.1.2466.6643.

[9] Kravets, V.V., Kravets, T.V. & Kharchenko, A.V. Using quaternion matrices to describe the kinematics and nonlinear dynamics of an asymmetric rigid body, Int. Appl. Mech., 2009, 45, (223). DOI 10.1007/s10778-009-0171-1.