ABSTRACT

of dissertation for the Philosophy Doctor (PhD) degree in specialty
“6D060300-Mechanics”

BIZHANOVA SALTANAT

THE TRANSLATIONAL-ROTATIONAL MOTION OF AN AXISYMMETRIC BODY OF VARIABLE MASS AND SIZE IN A NON-STATIONARY CENTRAL GRAVITATIONAL FIELD

General description of work

In classical celestial mechanics, real celestial bodies are modeled by a material point (spherically symmetric body) with constant mass. In cases where such a description does not properly represent the nature of the real physical problem, celestial bodies are modeled by a solid body of constant volume, mass, and structure. As is known from theoretical mechanics, the motion of any solid body consists of translational motion of its mass center (inertia center) and rotational motion around the inertia center. The modern theory of translational-rotational motion of absolutely solid celestial bodies is one of the main sections of classical and celestial mechanics and cosmodynamics.

Theory of translational-rotational motion of gravitating solid celestial bodies is one of the main modern sections of theoretical and celestial mechanics. Its difference is that the translational and rotational body motions are considered taking into account their interaction. One of the main problems of this theory is the problem of two solid bodies motion. The first partial solutions of the spatial two-body problem were found by G.N. Duboshin and named “spoke”, “arrow”, “float”. A major contribution to the theory of translational-rotational motion was made by Y.V. Barkin, S.G. Zhuravlev, V.V. Vidyakin and Kazakhstan scientists J.S. Erzhanov, A.A. Kalybaev, A.A. Baimukhamedov and their students.

Observational astronomy shows that real celestial bodies are not absolutely solid bodies - they are nonstationary, their masses, sizes, shapes and a number of other physical characteristics change with time in the process of evolution. In this regard, the creation of mathematical models of the motion of unsteady celestial bodies is one of the actual problem.

As follows from the theory of the stellar internal evolution, stars experience significant contraction and expansion at different stages of development. For example, during the transition to the red giant stage, the size of stars, depending on their mass, can increase by a factor of 10 to 100. Star clusters evolving against the background of a gas or stellar cloud are generally in a pulsation condition.

In order to describe the evolution of stars, a characteristic function is introduced, which gives the response of the star (change in radius) to a change in mass. When the mass of a star changes, the change in its size is studied. Changes in mass, size, and shape are evident in physically variable stars – pulsating stars.

Especially intensively the dissipation and mass transfer processes, changes of shape and sizes of components occur in close binary systems.

Different combinations of dynamical effects of nonstationary gravitating bodies, for example, of variable mass, shape, and size, show different ways of gravitating systems evolution. Studying these phenomena from the viewpoint of celestial mechanics shows the nature of the dynamical evolution of galactic, stellar and planetary systems.

Works of V. G. Fesenkov, G. M. Idlis, T. B. Omarov, J. D. Hajidemetriou, L. G. Lukyanov, E. N. Polyakhova, A.A. Bekov, A. Deprit, L. Floria, etc. highlight the special significance of nonstationary celestial-mechanical model problems in investigating the nature of unsteady space systems.

One of the important problems in this field is the unsteady two-body problem with variable mass and variable inertia moments.

T.B. Omarov and A.A. Bekov integrated a problem of two stationary centers in the presence of a variable gravitational constant and a driving drag force using the Hamilton-Jacobi method in ellipsoidal coordinates.

M.Zh. Minglibaev proposed a new intermediate motion to study the point mass motion around a constant spheroidal body of variable size and mass, the canonical perturbation theory of unsteady gravitational systems. A.A. Bekov in his work proposed a general intermediate motion at variable state of mass, size and shape.

Actuality of the theme.

Observational astronomy shows that real celestial bodies are nonstationary. Their masses, sizes, shapes and structures of mass distribution inside the bodies change with time. Especially intensively the dissipation and mass transfer processes, changes in the shape and size of components occur in close binary systems. Accordingly, their gravitational coupling becomes variable and the Newtonian interaction potential turns out to be clearly time-dependent. These factors significantly influence their dynamical evolution. In some stages of the evolution of gravitating systems the effects of nonstationarity of the bodies included in the system become the leading factors, and the further course of events is determined by the state of the system at the end of this stage. At present, one of the topical issues is the analytical and numerical study of the translational-rotational motion of two mutually gravitating unsteady celestial bodies using various methods of theoretical and celestial mechanics.

The main goal of work – study the equations of secular perturbations of an axisymmetric body, when the masses of the bodies vary isotropically at different rates and identify the effects of mass variability on their dynamic evolution, as well as obtain graphs of the evolutionary equations.

Research tasks

1. Obtain differential equations of translational-rotational motion of the axisymmetric body of variable mass and size in a relative coordinate system.
2. Obtain equations of secular perturbations of a nonstationary axisymmetric body in analogues of the Delaunay-Andoyer osculating elements.
3. Analysis of the complete system of equations for secular perturbations.
4. Analytical analysis of the secular perturbation equation and conclusions.

5. Numerical solution of the equation of secular perturbations and obtaining graphs, comparison of cases with constant and variable mass.

6. Construction of three-dimensional graphs of the first integral.

The object of the research

Translational-rotational motion of the nonstationary axisymmetric body in the gravitational field of the nonstationary sphere.

Research methods

The work widely uses methods of canonical perturbation theory of nonstationary gravitating systems, modern methods of computer algebra Mathematica and numerical methods.

Scientific novelty of the dissertation results

The dissertation work used equations of motion and well-known methods of perturbation theory to study the translational-rotational motion of the nonstationary axisymmetric body.

Equations of secular perturbations of the nonstationary axisymmetric body in analogues of the Delaunay-Andoyer osculating elements are obtained.

An analytical analysis of the equations of secular perturbations has been carried out. A numerical solution to the equation of secular perturbations is obtained. The solutions obtained in the dissertation work can be considered as the first approximate movement in the study of complex problems encountered in celestial mechanics.

The main provisions for the defense

1. A system of twelve equations of secular perturbations has been obtained, which splits into subsystems of four equations with one first integral and the rest. The system of four equations was qualitatively studied and the corresponding conclusions were drawn.

2. The above geometric and mechanical interpretations of the physical formulation of the problem we are considering are general properties for any initial values and any functions describing the mass and dimensions of the problem under consideration.

3. The resulting secular equations of motion were solved numerically and plotted using the Wolfram Marthematica package.

The reliability and validity of the results

The results of the dissertation coincide with the data of the theory of translational-rotational motions of solid bodies, obtained by other authors in the case when the masses and sizes of bodies are constant. In addition, the reliability and validity of the results are confirmed by the presence of publications in foreign journals with high impact factor.

Theoretical and practical importance of the dissertation

The results obtained in the dissertation work are the next step in the study of nonstationary systems in cosmology and further clarify the formulation of new problems for the study of complex nonstationary phenomena in the Universe. And the scientific significance lies in the fact that the new solutions found can be used in calculating a model of the dynamic evolution of artificial and natural satellites of celestial bodies.

Approbation of the dissertation

1. M. Minglibayev, S. Bizhanova. Study of the translational-rotational motion of two axisymmetric nonstationary bodies // International scientific conference of students and young scientists "Farabi world". – 2019.

2. M. Minglibaev, S. Bizhanova. Translational-rotational motion of an axisymmetric satellite with a variable compression ratio // XLIV Academic Readings on Cosmonautics. – Moscow. 2020. – T. 1. – P. 310-312.

3. M. Minglibaev, S. Bizhanova. Translational-rotational motion of an axisymmetric satellite of variable mass and size in a nonstationary central gravitational field // IX Polyakhov Readings, Proceedings of the International Scientific Conference on Mechanics. – Saint Petersburg. – 2021. – P. 152-154.

4. M. Minglibayev, A. Prokopenya, S. Bizhanova. Analysis of evolution of a nonstationary axisymmetric body in a nonstationary central gravitational field // 8th International Congress of Serbian Society of Mechanics. Kragujevac, Serbia. – 2021.

5. S. Bizhanova. Evolution Equations of Translational-Rotational Motion of an Axisymmetric Satellite with Variable Oblate // International Conference of Application of Computer Algebra (ACA-2021). – 2021. – P. 108.

6. A. Prokopenya, M. Minglibayev, S. Bizhanova. Secular perturbations of translational-rotational motion of a non-stationary axisymmetric body in the central gravitational field // Computer Algebra in Scientific Computing (CASC 2021)

Publications

Thomson Reuters or Scopus database:

1. S.B. Bizhanova, M.Zh. Minglibayev, A.A. Prokopenya. A Study of Secular Perturbations of Translational-Rotational Motion in a Nonstationary Two-Body Problem Using Computer Algebra // Computational Mathematics and Mathematical Physics. - 2020. - Vol. 60. - №. 1. - P. 26-35. https://doi.org/10.1134/S0965542520010054

Publications recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan:

1. M. Minglibayev, S. Bizhanova. Differential equations of translational-rotational motion of two nonstationary axisymmetric bodies // Vestnik KBTU. Series "Physico-mathematical and technical sciences". – 2019. – Vol. 16. – No. 2. – S. 143-149.

2. M. Minglibayev, S. Bizhanova. Study of evolutionary equations of a symmetrical body of variable mass and size // Vestnik KazNPU im Abaya. Series "Physico-mathematical science". – 2020. – Vol. 69. – No. 1. – S. 251-257.

3. M.Zh. Minglibayev, S.B. Bizhanova. Translational-rotational motion of a nonstationary axisymmetric body // News of the National Academy of Sciences of the Republic of Kazakhstan. – 2021. – Vol. 336. – № 2. P. 131-137.

In materials of international scientific conferences in foreign countries:

1. A.A. Prokopenya, M.Zh. Minglibayev, S.B. Bizhanova. Investigation of the Evolution Equations of the Two-Body Problem with Variable Masses // Computer Algebra Systems in Teaching and Research. – 2020. – Vol. IX. – P. 204-219.

2. M. Minglibayev, A. Prokopenya, S. Bizhanova. Analysis of Evolution Equations of a Nonstationary Axisymmetric Body in a Nonstationary Central Gravitational Field // 8th International Congress of Serbian Society of Mechanics Kragujevac, Serbia, June 28-30, 2021. – P. 638-647.

The personal contribution of the author

The main results of the research presented in the dissertation work were obtained by the author independently. The author of the dissertation performed work on averaging and obtaining differential equations of secular perturbations and a review of the literature, analytical analysis of the equations of secular perturbations and conclusions, equations of secular perturbations were numerically solved and graphs were obtained, cases with constant and variable mass were compared, three-dimensional graphs of the first integral were constructed. The formulation of the problem and discussion of the results were carried out jointly with scientific consultants.

The scope and structure of the thesis

The dissertation consists of the introduction, three sections, the conclusion, the list of references and two appendices.