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Lunar investigations at the Kazan University: the physical libration – analytical and numerical approach, the lunar coordinate systems

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Abstract

The theory of physical librations is one of traditional field of investigation at the Kazan University. At the present time it is necessary to develop the model of lunar rotation in order to achieve in the theory the accuracy of 0.1 milliseconds of arc, which is the requirement of modern laser ranging observations and other experiments to determine the parameters of the physical libration.

Both numerical and analytical approaches are very important, since the first provides greater accuracy, and the second - allows a qualitative analysis of the observed data, revealing features that are sensitive to the different physical phenomena that affect the rotation of the Moon.

In particular, the analytical theory has found effective application in computer simulating a new type of observation, such as the ILOM [1], with the purpose to estimate possibilities of the experiment.

One of the important application of the libration theory is the developing the selenocentric coordinate system useful for navigation tasks in the near-moon space. Such kind of the system the Union Selenocentric Reference System was constructed at the university on the basis of absolute coordinates of lunar craters, obtained with simultaneous photographing craters and stars.

1. Computer simulating the planned observation from the lunar surface

Over the past 10 years a creative cooperation has been formed between scientists of the Kazan University and the National Astronomical Observatory of Japan (Mizusawa). The project ILOM (In situ Lunar Orientation Measurement), planned in the frame of SELENE-2 or -3 missions, is aimed at obsevating the physical libration of the Moon. The Russian side has taken over some of the theoretical tasks to ensure the planned observations. One of the important elements of the project is placing of a small optical telescope on the lunar surface with the purpose to detect the lunar physical libration with millisecond accuracy [1].

Computer simulation of the future observations is being done with the purpose of their optimization: effective placement of measuring system on the lunar surface, testing of sensitivity of new observations to various features of the lunar interior structure. The results of the first stage of the simulation are presented. At this stage the software for the selection of stars and reduction of their coordinates onto the period of observations is developed, the tracks for the selected stars are constructed and analyzed, their sensitivity to the internal characteristics of the lunar body, in the first place, to the selenopotential coefficients, is tested [2-3].

Inverse problem of lunar physical libration is formulated and solved. It is shown that selenographic coordinates of polar stars are insensitive to longitudinal librations $\tau(t)$. Comparing coordinates calculated for two models of a rigid and deformable Moon is carried out and components of lunar libration sensitive to Love number k_2 are revealed [4].

Currently, the inverse problem is used by us to test the effect on the libration parameters of error in the coordinates of the observed stars. Preliminary calculations of the effect of errors in stellar coordinates show (see Fig. 1) that the error in 10 milliseconds in the ecliptical coordinates leads to a short-period variations of residual differences with a period of 1 month (27.23 days - the argument F) in 0.05ms $\Delta\rho$ and 0.3 ms in $I\Delta\sigma$.

Analytical theory of physical libration was very convenient tool for modeling the upcoming observations. The main outcome of this collaboration was the understanding of the strategy and tactics of building an improved analytical theory of physical libration.

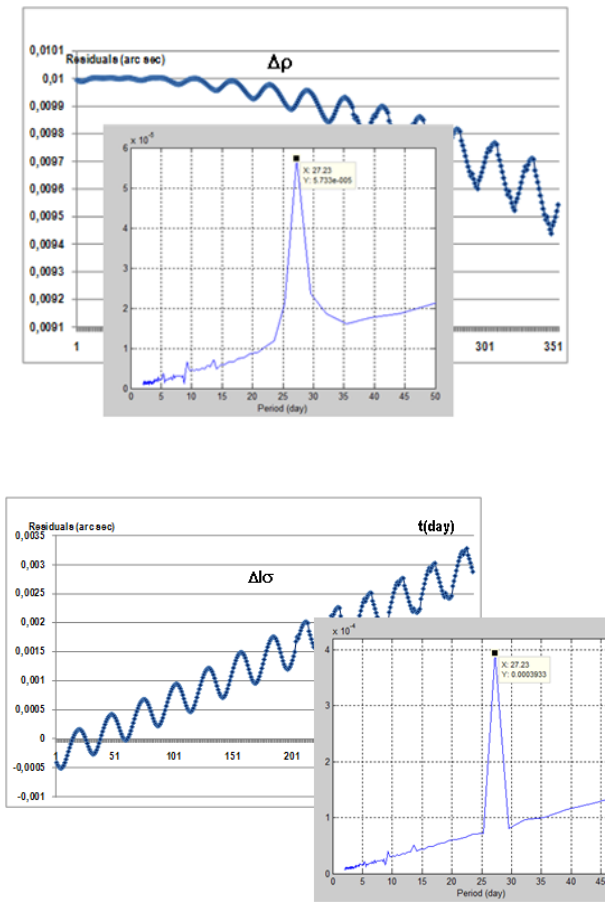

Fig. 1 Residuals arising due to inaccuracy of stellar coordinates

2. The first stage of numerical approach to construction of the libration theory

The urgency to develop numerical theory is also obvious. Ever-increasing accuracy of observations requires improving the theory describing the spin-orbit dynamics of the Moon. Analytical theory, for all its virtues, has inaccuracies inherent in the method itself for obtaining solutions. Moreover, the inclusion in the model of the lunar rotation dissipation effects of different origins, the presence of a two-layer core effects significantly complicates obtaining analytical solutions.

Numerical approach can give solution in such situations relatively fast, and sometimes it is the only way, to get information about the internal structure of the Moon and external factors affecting its dynamics. Dynamic ephemeris (DE) developed to the present time in the JPL NASA, are the standard that specifies the direction vector for developing the numerical theory.

To date, we have developed an integrator based on Runge-Kutta method of order 10, which in the solution of the linear problem of physical libration provides accuracy of 10^{-9} seconds in the interval of 10 years when compared with the exact analytical solution.

3. The Union Selenocentric Reference System

Three tasks were addressed in this research [5]:

a) the analysis of the mathematical model of the orthogonal coordinate transformation accuracy;

b) the identification of the basic dynamic reference system objects with ones that are contained in reducing catalogues;

c) the extension of the base points net of the basic dynamic reference system.

The construction of the system were performed using the developed software package "Transformation selenodesic coordinates" (TSC). During the processing, the following steps were carried out:

a) the analysis and investigation of the accuracy of the basic net contained in DSC;

b) the decryption of common objects for the coordinate systems that are being explored;

c) the extension of the mathematical content package TSC.

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