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Physical libration of the Moon: the results and the perspectives

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Beginning of the new millenium is marked by the reviews of results and problems in the field of lunar physical libration (LPhL) (Petrova, Gusev, 2001; Williams et al., 2001). The stage of investigation of the rotation of the Moon as a rigid body is finished by works of Migus (1981), Eckhardt (1981), Moons (1982, 1984), Petrova (1996). There exist two approaches in LPhL–theory, analytical and numerical ones. The latter is more accurate and allows to include more easily any modification of the rotation model. The main advantage of the analytical approach is the possibility to separate the forced and free librations. An improvement of the model of the lunar gravitational field with the aid of artificial lunar satellites, very high accuracy and amount of lunar laser ranging observations, effective mathematical and computer techniques permit to study many refined phenomena in lunar rotation and thus to take into account a complex interior composition of the Moon.

Analysis of LLR indicates that strong dissipation affects the rotation. Two possible sources of dissipation, solid–body tides and turbulent core–mantle boundary at a fluid core, are considered. The best fit to observations is achieved by means of numerical integration by taking into account the effects of tidal specific dissipation Q slowly increasing with period and small fluid iron core with the radius of 352 km or a core of Fe-FeS eutectic composition with radius 374 km (Williams et al.,2001).

Analytical theory of LPhL constructed by Moons (1982, 1984) is now completed by J. Chapront *et al.* (1999), by including the perturbations due to tidal effect (for elastic and anelastic models), indirect perturbations induced by the planets and by Earth figure and direct and indirect perturbations due to the ecliptic motion. For the first time Chapront *et al.* have added terms to the analytical solution for a forced part of the LPhL which depend on parameters of the free libration in the form of trigonometrical series. Coefficients and phases of the free libration were obtained by comparing with the laser observations and with the results of numerical integration. Due to the frequency analysis Chapront and Chapront-Touzé completed the analytical solution by a small number of trigonometric terms whose coefficients, frequencies, and phases are purely numerical. As result, the semi–analytical series of physical libration have been obtained. Residuals of this solution when compared with the ephemerides DE245 are below $0.03''$.

According to the theory of rotation of a two–layer body containing a solid mantle and a liquid core the new mode, called free core nutation (FCN), should appear in the polar rotation of the celestial body. The FCN phenomenon is a consequence of the fact that the core's rotation pole does not align with the mantle's pole. The FCN detection and its period in the rotation of the Moon will allow: a) to clarify the physical nature of the lunar core (FCN is possible only for the liquid core); b) to determine the core radius and its flattening; c) to determine the density jump at the core–mantle boundary and CMB flattening. The preliminary estimation of the FCN–period (Petrova, Gusev, 2001) gives the value of 144 years hardly accessible for ground–based observations owing to the small size, small ellipticity and slow rotation of the lunar core.

In this respect the planned Japanese space experiments In–situ Lunar Orientation Measurement (ILOM) can help to discover even such long–period variations with small amplitudes, which may have the FCN frequencies. ILOM Research Group (Heki et al, 2000) are proposing the in-situ measurement of the physical libration with the optical telescope at the lunar pole as one of the missions in the second SELenological and ENgineering Explorer (SELENE 2). A telescope with lens of 20 cm in diameter, 2 m in focal length is equipped with a 4000×4000 CCD array to determine the stellar positions accurate to one milliarcsecond and a mercury pool that compensates the tilt of the telescope. The scientific targets of ILOM project are the investigation of physical properties of the Moon Q, k_2, R_{core}, core density, density jump at the CMB and CMB flattening, excitation and maintenance mechanism of the free libration and free core nutation, core–mantle different rotation. For successful determination of the FCN–parameters a further detailed elaboration of the analytical theory of physical libration of the two–layer Moon is required.

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