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Actual problems of selenodynamics: the Moon rotation, tidal and non-tidal variations of selenopotential coefficients and possible displacements of center of mass of the Moon

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Abstract. Actual problems of modern selenodynamics and selenodesy are discussed in view of achievements by geodynamics and geodesy of last years and possible again opening prospects in modern researches of the Moon with the help of space vehicles.

1. Rotation of the Moon. Influence of a liquid core.

The problem of rotation of the Moon at all times will remain a central problem for selenodynamics and selenodesy. Its actuality increases with an increase of accuracy of observations. Now the laser ranging measurements of distances to the lunar reflectors achieves a millimetre level of accuracy **[1]**. A phenomenal accuracy of measurements of orbits of a complex of satellites of the Moon is achieved by the Japanese lunar mission KAGUYA (SELENA). The accommodation of the zenith telescope in polar region of the Moon is planned in close future (Japanese project ILOM), and creation and functioning of manned scientific bases on the lunar surface **[2]**.

This colossal technical progress shows increased requirements to the theory of librations of the Moon. Completely necessary the account of features of its real structure, presence of a liquid core already is and it is possible a rigid core, elastic and dissipative properties and other physical properties of the Moon shells. In this connection now we work on construction of the analytical theory of rotation of the Moon with liquid ellipsoidal core and elastic (rigid) mantle **[3]**. In particular it was shown, that influence of a liquid core a radius in 350 km is shown in increase of amplitudes of the Moon librations in a longitude approximately on 0.06 %. For example, the contribution of a core to amplitude of the basic librations in a longitude (with the annual period), estimated in 90”7, makes about 0”054. It makes in principle basically a value which can be determined from observations. The period of free librations of the Moon in a longitude due to the influence of the liquid core decreases on 0.03 % (i.e. approximately for 0.32 day), and the period of free pole motion of the Moon is increased (for the same dynamical reason) by 0.095 % (approximately for 25.8 days). The period of free precession of a vector of the angular momentum of the Moon, as well as key parameters of motion of the Moon on Cassini’s laws, as a first approximation are not subject to influence of a liquid core. The dynamical interactions in the system “mantle-ellipsoidal core” tests also the new oscillations with the "quasi-diurnal" - with the period of free core nutation. This period was estimated by us approximately in 27.1646 day **[3]**.

The developed model takes into account the gravitational moments of the Earth, the Sun and planets at the precision description of their orbital motions. Perturbations in the moon rotation of the first order caused by influence of the second harmonic of selenopotential have been obtained in analytical form, in details investigated and tabulated. The mentioned perturbations have been obtained for wide group of variables.

2. Tidal and non-tidal deformations of lunar surface.

The accuracy of determination of horizontal displacement of points of a lunar surface by the Moon librations relatively a mean direction to the Earth makes about 8-17 mm **[1]**. Tidal deformations of lunar surface are described by the sum of certain periodic components. The bigger vertical displacement is characterized by amplitude about 10 cm and by anomalistic period in 27.555 d. Other significant tide has the period 27.212 d (the period of passage of node of lunar orbit on ecliptic). Others tidal deformations of the solid Moon with amplitudes about centimetre are characterized by the periods in 1 and 1/2 months, and with amplitudes about millimetres are characterized by the periods: 1/3, 7 months, 1 year

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and 6 years. Horizontal tidal displacements of points of lunar surface are characterized by amplitudes approximately twice smaller in comparison with mentioned above. Solar tides on amplitude reach 2 mm. The third harmonic gives tides with small amplitudes less than 1 mm. Polar (rotational) tide **[1]** have the same order.

Due to eccentric positions of the main shells of the Moon it is necessary to expect not adequacy in application of the classical theory of de formation for elastic spherical celestial body with concentric distribution of density. Accordingly, determination of Love numbers with using of this theory of elastic deformations of the Moon can give essential divergences with data of observations - in particular at interpretation of the data on deformations of lunar surface on the seen and foreside of the Moon. Therefore the theoretical problem about deformations of an elastic planet with eccentric positions of base shells in a gravitational field of external celestial bodies is rather actual. The values of Love number k_2 obtained at study of observable variations of a gravitational field of the Moon and on the basis of the classical theory of tides, are characterized by significant distinctions and errors **[1]**, **[4]**. Our studies have been shown, that in selenodynamics and selenodesy the mechanism of gravitational excitation of the system of non-spherical and eccentrically shells of the Moon by external celestial bodies can play an essential role **[5]**.

3. Mechanisms of deformations of the Moon and oscillations of its centre of mass. The phenomenon of oscillation of the centre of mass of the Moon can be revealed from observations in the near future. It is possible to specify two facto rs which by all means cause oscillations with a wide spectrum of frequencies and the certain properties. First, terrestrial and solar tides on the Moon have asymmetrical character and can results in appreciable displacements of the centre of mass at variations of distance between the Earth and the Moon. The principal cause consists that shells of the Moon (including core) are non-concentric, and occupy eccentric positions. The centers of mass of shells of the Moon are not coincide and are essentially carried. As an example, we shall specify an asymmetric structure of a crust of the Moon: on the part of the Earth it approximately is twice more thin, than from the opposite side. Accordingly tidal "bulges" in a crust (and in other shells) here any more will not be symmetric as it takes place in classical theory. Masses of asymmetric bulges will vary cyclically in dependence on position on the Moon and from distance between the Moon and the Earth. We can assume, the centre of mass of the Moon will be displaced cyclically relatively its crust in particular with anomalistic period 27.555 d, and mainly along a direction to the Earth. For detailed studying of this question the new development of the theory of tides for the class of bodies similar to the Moon, consisting from the system of eccentric shells, it is required.

The attraction of the Earth produces various gravitational actions on the core and more non-spherical mantle of the Moon. On a rough estimate geometrical oblatenesses of a surface of the Moon and its core make approximately $(c-a)/a=-13\cdot 10^{-4}, (c_c-a_c)/a_c=-2\cdot 10^{-4}$, and are remarcably different. Here c, a and c_c, a_c are polar and equatorial semi-axes of approximating ellipsoids of the lunar surface and core surface. As it was marked in work **[5]** the inner shells are more concentric in comparison with external shells. And it means, that the mantle treats to action by essentially bi gger gravitational momentums than a core. As a result of differential action of external celestial bodies on "unequal" shells there are their additional relative interactions against each other, displacements and mutual turns, accompanied with deformation s and accumulation (or reduction) of elastic energy. Not only the moments of forces influencing on relative turns of the shells play important role, but also the forces of interaction of shells with each other. External celestial bodies as though force she lls of the Moon, or to "impact, an attack" against each other, or to time "deviation, rest" **[5]**. The forced interaction of these shells has cyclic character as force of interaction between them depends on distance the Earth - the Moon. A direction of this force again close to a direction to the Earth. Thus, and this mechanism **[5]** also results in the swing and wobble of the core (or the lower mantle as a whole) relatively to the more elastic mantle (or upper mantle).

We assume that oscillations of the core-mantle system have nonlinear character because of not trivial their interaction at core-mantle boundary

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and at boundary of the upper and supper mantles of the Moon (a boundary is approximately at the depth 1000 km). It means, that actually in oscillations of the mentioned shells must be observed oscillations with periods multiple to anomalistic, sinodic and draconic periods (and others). These conclusions are clearly confirmed by spectral analysis of temporal variations of the lunar seismic activity of the Moon, which on our geodynamical model **[5]** is controlled and induced by the relative oscillations and wobble of the Moon shells **[6]**.

Conclusions. Due to outstanding achievements of space missions to the Moon (KAGUYA, Lunar Express etc.), there are quite real the direct determinations of cyclic (and secular also) variations of selenopotential coefficients (for low harmonics), more detailed description of tidal and non-tidal deformations of lunar surface, in particular researches of global planetary effects in change of opposite hemispheres of the Moon and in displacement of its centre of mass. New statement of a problem about librations of the Moon with the displaced (eccentric) liquid core deserves steadfast attention and is actual. Dynamic effects caused by a eccentricity of the core can be remarkable and basically can be observed at precision laser observations with millimetre accuracy.

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