DETERMINATION OF THE STRUCTURAL AND MECHANICAL PROPERTIES OF THE LUNAR SOIL BY THE AUTOMATIC LUNAR STATION "LUNA-13"

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The instruments carried on board the spacecraft "Luna-13" for determining the density and mechanical strength of the lunar soil and their ground calibration are described briefly. Some results of the experiment are presented.

The principal objective of the automatic lunar station "Luna-13" was to conduct the first determination of the density and penetration resistance of the surface layer of lunar soil using instruments deployed at the landing site (Fig. 1).

The determinations were made with a mechanical soil-gauge penetrometer and a radiation densimeter operating independently.

In designing and calibrating these instruments and working out methods of decoding the telemetry from the moon it was necessary to solve some complicated problems associated with the maximum minaturization of the apparatus, the choice of materials for simulating the lunar soil, and allowance for the effect of the irregularities of the lunar surface.

For example, the penetrometer, which weighed 70 g on the moon, developed an indenter load 100 times greater than its weight, while the complicated electronics of the radiation densimeter were squeezed into a space measuring 1.5 dm^3. The experience acquired in developing these intruments will undoubtedly be useful in designing similar apparatus for terrestrial scientific and surveying expeditions.

The penetrometer (Fig. 2) was intended for estimating the mechanical strength of the soil. It consisted of a plastic housing, the lower part of which formed a flat ring measuring 7.15/12.0 cm in diameter, and a titanium indenter with a conical head. The indenter cone angle was 103°, the maximum diameter of the cone 3.5 cm. The indenter could be extended up to 5 cm. The displacement relative to the housing was measured with a potentiometer that delivered a signal to the telemetry system.

The upper part of the indenter served as the case of a solid-propellant rocket motor with the nozzle turned upward. The command to ignite the motor was sent after the spacecraft had landed, opened its petals, and deployed the instrument. Under lunar conditions the motor burns for about 0.8 sec with thrust of about 6.5 kg.

The depth of penetration of the indenter was radioed back to earth, and subsequent interrogation of the system provided information about changes in the position of the indenter with time.

The instrument was calibrated on materials that simulated the assumed nature of the lunar surface. Altogether, 14 materials were employed, starting with a very strong porous andesite-basaltic lava and ending with a light expanded perlitic sand; the properties of these materials reflect the assumed properties of lunar soils ranging from rock to dust. Artificial as well as natural materials were tested, for example, foam, concrete, foam glass, agloporit, etc.

The results of the ground calibration tests are presented in the table.

In order to ascertain the effect of the special conditions existing on the moon, tests were conducted in a vacuum chamber and the dependence of the depth of penetration of the indenter on the acceleration of grav-

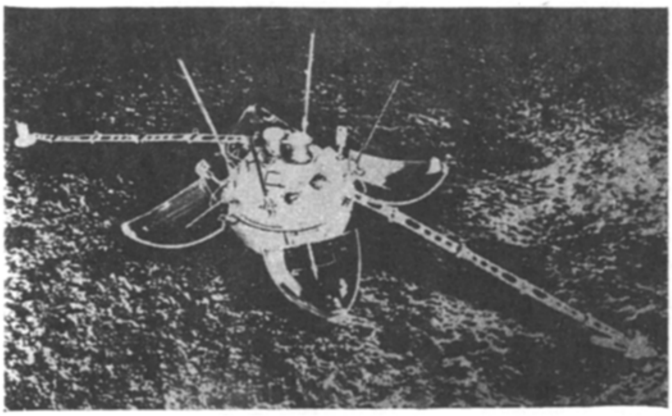

Fig. 1. The automatic lunar station "Luna-13." Center, the spherical spacecraft; left, the extensible mechanism for deploying the soil-gauge penetrometer; right, the extensible mechanism for deploying the radiation densimeter detector.

ity was also investigated (in an aircraft flying a trajectory along which the acceleration was equal to the lunar gravity). It was found that as a result of the reduced gravity the depth of penetration into the tested soils is increased on average by 70%. Because of the vacuum conditions the motor thrust is 8.5% greater than its value on the ground.

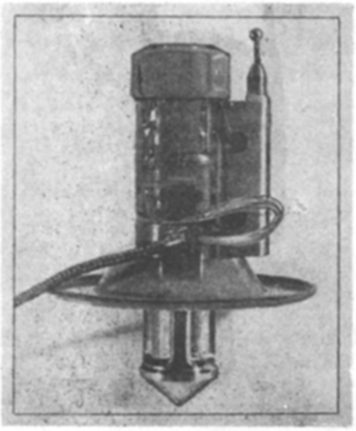

Fig. 2. External view of the soil-gauge penetrometer with indenter extended.

The radiation densimeter was intended for determining the density of an upper layer of the lunar soil up to 15 cm thick. It consisted of a detector (Fig. 3), attached to an extensible arm and applied directly to the lunar surface, and an electronics unit carried inside the spacecraft and designed to process the information from the detector and transmit it to the telemetry system.

The detector contained the radioactive isotope cesium-137 with an activity of 1 mg · eq radium, a lead shield, and three groups of gamma counters. The operating principle of the densimeter is as follows: gamma quanta emitted by the isotope interact with the soil. Some are absorbed by the soil, while others, after multiple scattering, return to the detector and are registered by the counters. The relation between the intensity of the registered scattered radiation and the soil density corresponds to a parabolic curve that is convex upward and has a maximum at a density of 1.5 g/cm^3. The ascending branch of the curve corresponds to materials with densities from 0.1 to 1.5 and the descending branch to materials with densities from 1.5 to 2.6 g/cm^3 (in terrestrial units).

Accordingly, any counter reading corresponds to two density values—less than and greater than 1.5 g/cm^3. Since it is improbable that there are materials of density greater than 1.5 g/cm^3 on the lunar surface, the density on the ascending branch of the curve was selected.

Before being installed in the spacecraft the radiation densimeter was calibrated on the material described above, whose density varied from 0.50 to 2.26 g/cm^3.

In order to carry the penetrometer and densimeter clear of the part of the surface deformed by the impact of the spacecraft and to bring them within view of the television camera, they were mounted on special extensible arms with four articulations. These arms were equipped with a cable synchronization system to ensure the simultaneous proportional deployment of all the links followed by complete straightening and the smooth lowering of the instruments to the soil at a distance of 150 cm from the spacecraft proper. The penetrometer and densimeter were attached to forks hinged to the ends of the arms. The axis of rotation of the instrument relative to the fork and the axis of attachment to the arm formed a Cardan coupling designed to permit the orientation of the instruments and close contact with the uneven surface of the moon.

The panorama of the lunar surface photographed on 24 December 1966 shows the articulation of the first and second links of the arm mechanism, the last link, the radiation densimeter detector, and a sharp shadow of the mechanism showing that it had deployed normally.

Since lunar panoramas recorded by the spacecraft "Luna-9" and "Luna-13," together with the photographs taken by "Surveyor 1," have shown that the lunar surface abounds in numerous fine irregularities in the form of stones and small depressions, which may distort the readings of instruments designed to operate on a level surface, we investigated the probability of obtaining useful information from the instruments described. For this purpose we analyzed the information on the microrelief of the lunar surface (maps and tables) published in [1].

If the instrument housing were to descend on a stone or depression, a gap would be formed between the soil surface and the instrument, which in most cases would lead to an underestimate of the mechanical strength

Results of Calibration Tests on Soil-Gauge Penetrometer Under Terrestrial Conditions

Depth of penetration, cm		Density of model material, g/cm^3	Natural and artificial model materials
indenter	housing		
0	0	2.4 or more	Dense rock. Heavy concrete
0.0—1.3	0	0.25—2.0	Vesicular and porous rock. Cohesive soils. Foam concrete, foam glass, porous clay filler with organic binder
1.3—5.0	0	1.3—1.7	Noncohesive granular soil of medium density.
1.3—5.0	0—1.0	0.25—0.77	Noncohesive granular soil of low density. Crushed foam, concrete, porous clay filler, agloporit
5.0	more than 1.0	0.16 or less	Very loose, dusty soil. Expanded perlitic sand

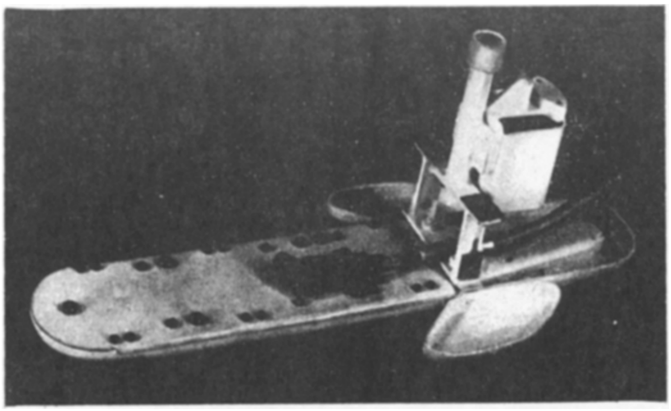

Fig. 3. External view of radiation densimeter detector.

and density. On the assumption that 12 mm is the maximum permissible gap at which it is still possible to distinguish between solid, granular, and dusty surfaces from the penetrometer readings, it was established that the so-called "total defective area" was about 30% of the entire surface in the vicinity of the spacecraft "Luna-9." Around "Luna-13" the surface was more even.

The total defective area is the sum of the area occupied by stones and depressions and the surrounding annular areas of width equal to half the width of the instrument housing plus the sum of the individual areas around points at which a sharp break occurs in the inclination of the surface between stones and depressions. Bearing in mind that these calculations are approximate, we may assume that the presence of irregularities may lead to 30% erroneous measurements, i.e., 70% of the results would be reliable.

A study of the part of the lunar panorama showing the radiation densimeter indicates that the latter was deposited on a relatively even surface, flattening it slightly, and was evidently in close contact with the soil.

An analysis of the telemetry revealed the following.

1. When the motor fired, the indenter of the penetrometer was extended 4.5 cm, subsequent interrogations of the system indicating displacement in the range from 4.17 to 4.33 cm, probably as a result of temperature deformations of the spacecraft and extensible arm. On earth, allowing for the lunar vacuum and reduced gravity, the penetration of the indenter into the same woil would have been about 2.6 cm. This corresponds to the operation of the instrument on an even surface of noncohesive heavy sand with a density greater than 1.5 g/cm^3 or on a slightly cohesive, light, porous material of the agloporit of clay filler type with a density of 0.75–0.77 g/cm^3.

2. The intensity of the scattered radiation registered by the detector of the radiation densimeter, with allowance for the lunar gamma-radiation background, corresponds to a surface-layer density of 0.8 g/cm^3 on the ascending branch of the calibration branch or 2.1 g/cm^3 on the descending branch. Rejecting the latter value as improbable, we arrive at a density of 0.8 g/cm^3, which indicates a light, granular, porous material.

To summarize, we conclude that at the landing site of "Luna-13" the surface evidently consists of a layer of loose, slightly cohesive, granular material with a density of about 0.8 g/cm^3, consisting of grains and granules of porous mineral matter weakly bound together at the contact points. The thickness of this layer beneath the penetrometer is not less than 5 cm. Stones of various sizes, visible in the panorama, are scattered over the surface.

REFERENCE

1. First Panoramas of the Lunar Surface [in Russian], Izd. Nauka, AN SSSR, 1967.

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