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# Chapter 12

# The First Control System for Space Vehicles[1]

**Boris V. Rauschenbach**[2]

The year 1989 marks 30 years since the first controlled space vehicle was launched into interplanetary space. The Soviet automatic probe, *Luna-3*, went up on 4 October 1959, looped the Moon, aimed on-board photo cameras at the far side of the Moon and transmitted back to Earth the first sensational pictures of the far side of the Moon, which no one had ever seen before the advent of the Space Age.

Work on controlling the flight of spacecraft began in the U.S.S.R. in 1954-1955, so that by dawn of the Space Age in 1957 broad outlines of the future guidance systems were discernible.

Like their U.S. counterparts, Soviet scientists began by tackling the most vital and, in a sense, simple task: the development of an attitude control system designed to control the position of the axes of spacecraft relative to celestial reference points. This type of control was required for aiming photo cameras at the desired heavenly body.

During the development of an attitude control system for *Luna-3*, Soviet space scientists sought to produce a system that would be the ultimate in design simplicity and reliability. So the design principles to be followed had to be so obvious as to dispense with extensive preliminary studies and the time-consuming development of sophisticated instrumentation. Besides, the system under development needed to function for only an hour of actual photography. This made the task easier, and it was perfectly natural for the first-ever attempt at active control of a space vehicle.

Any attitude control system, as we now know, is a combination of pick-ups that create control moments and instruments which generate control signals in response to

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[1] Presented at the Twenty-Third History Symposium of the International Academy of Astronautics, Málaga, Spain, 1989.

[2] The Soviet National Committee on the History and Philosophy of Science and Technology, Moscow, U.S.S.R.

signals transmitted by the sensors. These devices had to be as simple as possible in design and totally reliable.

As for the control moments, it was decided to obtain these by means of tiny nitrogen thrusters using compressed nitrogen. This, of course, was the simplest of solutions. In theory, tiny thrusters burning liquid propellant could also be used but would require much time to develop and test. The use of a cold compressed gas was justified under the circumstances, since the small size of *Luna-3*, and the brief period of active functioning, required only a limited quantity of compressed nitrogen (a mere 1.08 kg). The use of compressed nitrogen, instead of a fuel, continued later when Vostok-class spacecraft arrived on the scene. The switch over to the use of liquid propellant for attitude control systems began with the Soyuz series of spacecraft. The record of space exploration since indicates that the switch over was a sound move.

The development of sensors and pick-ups was facilitated by the fact that the flight program of *Luna-3* called for photographing the far side of the Moon in full phase. Understandably, we wanted to obtain as much information as possible on as big a portion of the far side of the Moon as possible (with lateral illumination by the Sun the lunar relief would appear bolder, but the other half of the far side would be in the shade). The photography method chosen ensured that during the shooting session the spacecraft would be on an imaginary straight line linking the centers of the Sun and the Moon. This helped to develop an extremely simple logic for aiming the camera at the Moon.

The camera's axis was directed along the symmetry axis of the body of the spacecraft, on one side of which was a porthole through which photography was to be conducted. The opposite side of the spacecraft was "sunny" and had to be directed towards the Sun during the photography session, due to the mutual position of the Sun, the Moon and the spacecraft.

Now the Sun is such a bright star that the direction from which the Sun's rays come can be found by simple means. A set of eight photo diodes (electronic devices activated by sunlight) were arranged on the surface of the spacecraft in a way to ensure a spherical field of view (with any position of the spacecraft relative to sunlight at least one of the sensors was exposed to it). There was only one exception to this rule, namely, when the "sunny" side of the spacecraft was exposed to direct sunlight (to within ± 5°), all solar sensors were in the shade (this was achieved through the use of "visors" positioned next to them).

The logic of the firing sequence for tiny thrusters that provided attitude control was designed to ensure that, irrespective of its initial position, the spacecraft would eventually expose its "sunny" side to the Sun. The disappearance of the sensor exposure signal indicated the completion of this phase, whereupon the porthole opened and the camera was pointed at the Moon. A more accurate positioning of the camera's optical axis at the center of the Moon was achieved through a special lunar sensor placed next to the camera. The accuracy of this aiming was within ± 0.3°. Unlike solar sensors, the lunar sensor was a pretty sophisticated optical device. The attitude control system was capable of maintaining the camera's optical axis directed at the center of the Moon, with the accuracy indicated throughout the prearranged period of operation.

To ensure successful operation of the system for pointing the axis of the subsequent retention in the desired position, rate gyros had to be used, quite apart from optical sensors. A set of three rate gyros were set up on *Luna-3*. These signaled the sign of the angular velocity, and their sensitivity was 0.002-0.08 degrees per record.

Control signals were generated in a special unit following a very simple logic: upon deviation of the axis of the spacecraft from the pre-set direction, the right attitude-control thruster was fired. This could be fired either in a continuous (in the event of considerable deviations) or pulse mode (when it would be fired for brief periods at a firing rate of about 1 Hz).

As this brief description shows, the attitude control system featured an extremely simple and straightforward design. When the system was under development, there was no experience in controlling space vehicles. That is why it was deemed essential, despite the system's simple design, to test it fully under laboratory conditions. A special dynamic test facility was set up for the purpose. The test facility made it possible for a horizontal platform to perform free rotations around a vertical axis, with rotation resistance so negligible that, against the background of the forces created by the tiny thrusters, it could be ignored. The rotating horizontal platform bore equipment that was identical to that used on board *Luna-3* during its mission to the Moon, and it included optical sensors, rate gyros, a compressed nitrogen cylinder complete with fixtures, thrusters, the logic module, etc. The solar and lunar radiation simulators were located outside the platform. Control regime modes "for the Sun" and "for the Moon" were tested at different times, obviously. The test facility made it possible not only to test the correct functioning of the proposed design configuration, but also to obtain dynamic characteristics of the spacecraft's control: the time of "looking for" the Sun, the nature of oscillations around the exposure to the Sun after the "sunny" side of the spacecraft had moved into position, the time for fine-tuning lunar orientation, the nature of oscillations around the aiming of the camera at the Moon during the photographing session, the actual accuracy of the aiming of the camera's axis at the center of the Moon, nitrogen gas consumption rates in different operating modes etc. This indicates that the tests made it possible to model, with a high degree of completeness, the entire attitude control process, using equipment identical to that used by *Luna-3*. This description shows that virtually simultaneous rotation modes of the spacecraft around the three axes (conditional rotations in pitch, yaw and roll) could be tested consecutively only. That this type of simplification was justified was proved by computer calculations.

From the standpoint of the history of space technology, development of the test facility described above is of interest, too. On the one hand, it showed that the developers of the first-ever attitude control system approached the task before them very seriously, while, on the other, it demonstrated how a total lack of previous experience of space flight could, to a certain extent, be made up by the acquisition of similar experience through well-designed simulation on the ground. These tests made it possible, in particular, to fine-tune the adjustment of certain components of the system and even to debug them. During the development of the attitude control system for use in photographing the far side of the Moon, dynamic tests largely confirmed the design (calculated) data. At the same time, this made it possible to introduce substantial adjustments, following a series of ground tests, into another attitude control system that was concurrently under development for the Vostok spacecraft. In due course, as more experience of space flight was gained, such ground tests were no longer necessary, since the experience made it possible to develop advanced techniques for calculating control processes.

We should add that the rotating platform also had a camera set up on it which photographed the lunar simulator, following the logic of the same automatic devices that would be used by *Luna-3*. As this particular camera was identical to the one on board the spacecraft, the entire photography process, including the search for the Sun, the aiming of the camera at the Moon, the subsequent maintenance of the camera's axis directed at the center of the lunar disc and, finally, the photography process itself, was tested fully on the ground.

Comprehensive and thorough tests enabled the scientists to gain full confidence in the fool-proof operation of all the systems involved in photographing the far side of the Moon. The pictures of the Moon simulator were visual evidence of the fact that both the aiming of the camera at the Moon, and its maintenance in the required position, were fully guaranteed by the attitude control system developed.

On 7 October 1959, the far side of the Moon was photographed between 06.30 a.m. and 7.10 a.m. Moscow Time, from a distance of 65,200 km (at the start of the photography session) and 68,400 km (at the end of it), using two cameras with a focal length of 200 mm and 500 mm, respectively. The first focal length provided a picture of the lunar disc that was fully in the frame, while the second provided a close-up picture of a part of the lunar disc (the photography was conducted using special 35 mm film with exposure times of varying length). The pictures transmitted back to Earth by *Luna-3* showed that the far side of the Moon differed substantially from its visible side. The main difference was the predominance of mountains on the dark side and the comparative lack of the mares which dominate the visible side of the Moon.

These photographs and their scientific description represented an epoch-making event in the development of astronomy. *Luna-3* ushered in a new chapter in the annals of this ancient science/planetary exploration by means of spacecraft. We now witness the impressive progress made by mankind in this direction: lunar landing, (including the landing of manned spacecraft on the Moon), the delivery of lunar rock samples to Earth, the mapping of Venus and Mars and the landing of planetary probes on the surface of both, deep-space planetary probes to distant planets and the exploration of Halley's comet. However, the first step on this rewarding track was made in October 1959.

From the standpoint of the evolution of space technology the flight of *Luna-3* was also the first venture into a new uncharted area. Until October 1959, only controlled space vehicles were in outer space, moving in orbits governed by the laws of celestial mechanics and slowly tumbling around their center. The first step in this area was to check the tumbling, replacing it with a goal-oriented, purposeful aiming of the spacecraft's axis at celestial reference points. This was followed by a landing maneuver (the Vostok spacecraft), maneuvers for mid-course correction of the trajectory in interplanetary probes, the approach and docking (rendezvous) of two spacecraft in mid-orbit, soft landings on zero-atmosphere planets, etc.

The development of the *Luna-3* spacecraft, and the results of its flight, marked the start of a new stage in the development of astronomy and space technology. This makes the 30th anniversary of this breakthrough worth marking.

The development of the probe's attitude control system was carried out by a team of young space engineers. It was my good fortune and privilege to lead the team. I would like to single out for special mention the contribution made to the success of the project by V. P. Legostayev, E. A. Bashkin and D. A. Knyazev.

In conclusion it would be useful to cite the basic technical characteristics of the attitude control system described in the present communication.

**Dynamic Characteristics**

| | |
|---|---|
| Accuracy of solar orientation | ± 5° |
| Oscillation period in solar orientation | 2 min |
| Accuracy of lunar orientation (per each axis) | ± 10' |
| Oscillation period in lunar orientation | 10 sec |
| Average angular velocities (around different axes) | from 0.03 to 0.10 deg/sec |

**Mass Characteristics**

| | |
|---|---|
| Mass of the pneumatic system | 13.6 kg |
| Mass of the logic module and rate gyros | 5.0 kg |
| Mass of the optical sensors | |
| Mass of the compressed gas | 3.1 kg |
| Gas consumption rates (design) | |
| for the initial checking of tumbling and solar orientation for 20 minutes | 0.25 kg |
| transition to lunar orientation and the maintenance of the lunar orientation for 45 minutes | 0.46 kg |

**Power Consumption**

| | |
|---|---|
| Rate gyros (3) | 3 W |
| Optical sensors (total) | from 1 W to 2 W |
| Average power consumption not greater than | 60 W |