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Chapter 11

The History of the First Stage of Spacecraft Control Systems Development in the U.S.S.R.*

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This article deals with the history of the initial phase of working out an attitude control system for space vehicles in the U.S.S.R., from the first theoretical research until the photographing of the far side of the Moon and the first controlled artificial satellites of the Earth.

Preparations for space exploration had started in the U.S.S.R. long before the beginning of the cosmic era, that is, October 1957. A number of research groups were formed, who studied (for the time being purely from the point of view of theory) the questions of terrestrial space from the artificial satellites of the Earth. It became instantly clear that a number of research works (for example those of astronomical character) could be performed only from those satellites, which will be the controlled ones, that is, they must be able to occupy a required attitude in space, that is, provided with attitude control system.

If we limit ourselves to studying the history of the initial phase of work on attitude control systems of the space vehicles, it turns out that fruitful theoretical research in this direction started in 1955, and it was concentrated in three centers. First, the work was carried out in the Polytechnical Institute in Leningrad

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supervised by Professor A. I. Luryie. The scientific interests of this group were concentrated on the studies of the complicated problems of the control dynamics when the space vehicle contains revolving masses (big gyroscopes), and rotates itself. Though this work was quite interesting, it was of rather abstract character, and it did not influence further work on creating the real systems. The second center was the Institute of Applied Mathematics in Moscow. Here, under the supervision of D. E. Okhotsimsky, they studied the possibilities of passive systems to keep the necessary attitude of a satellite by way of using the qualities of the Earth's gravitation field. It turned out that, if two large enough masses with the help of long poles could be located in such a position that the satellite is between them, then finally the whole system will take such a position that these two masses will be located on one vertical. It means that the satellite will have an absolutely definite attitude in relation to the Earth. Here we expose only the main idea of the method. But, to put such systems into effect, it is necessary to introduce damper devices into their composition, as well as a number of other auxiliary systems. The main advantage of such a method of obtaining a necessary attitude is the fact that, in order to maintain this attitude, neither energy nor mass expenditure were needed. Such systems got some practical application later on. The third center, which studied the problems of active attitude control systems, that is, those systems which require mass or energy expenditure for control, or both of them simultaneously, was situated on the premises of the Reactive Scientific-Research Institute in Moscow. The author of this article had the honor to supervise these works. It is necessary to note that research work on both passive attitude control and active attitude control was conducted under the general leadership of Academician M. V. Keldysh, therefore, they were to a certain extent coordinated and filled up for each other.

While working out active attitude control systems, as well as any other principally new systems, peculiar difficulties may occur. The difficulty is that there is no theory on the problems of controlling such vehicles which could serve as a kind of support. On the other hand, it does not seem possible to develop such a theory, as the structure of the system in question is unclear, thus, the theoretical questions which need solution are unclear as well. The only way to overcome this difficulty is a simultaneous working out of the whole system, and theoretical research of the problems, which occur in the process of work.

In order to start the work planned, it was decided to begin with working out a concrete attitude control system for the "OD" satellite, the work on which started in the design office headed by S. P. Korolev. At that time, this satellite was considered to be a distant prospect (as it was only 1955), nevertheless, the work began, as it was clear that constructing this satellite would take a long time. It was of utter importance for those who were engaged in working out attitude control systems that, as a basis, they could use mechanical characteristics of the OD space vehicle, the total mass of control system, which should not be surpassed, the maximum admissible energy consumption, obligatory control precision and some other data. This immediately and essentially limited the number of possible variants of the attitude control system, and it forced the researchers to look for non-traditional (that is, unknown in the practice of aviation and navy) solutions. Moreover, the technical side of these solutions should cause no doubts.

Preparatory work on the system was completed in 1956. This allowed S. P. Korolev to write the following words at the beginning of 1957: ". . . there has been carried out work, which proved that there exists a technical possibility to work out an active attitude control system of an artificial satellite."[1] Thus, the structure of future attitude control systems was quite clear a year before the first uncontrolled artificial satellite was launched to orbit the Earth. It is only now that the report on the work done in 1956, and sent to some institutions and firms which were interested in the project, is published.[2]

Non-traditional technical solutions, suggested at that time, could be summed up in three principle clauses. Vertical direction (i.e. direction towards the Earth) was to be defined with the help of a special optical device, using the infrared radiation of the Earth. In order to render the satellite in a necessary location in relation to the orbital plane, a gyroscopic device was invented, which in some distant ways reminded of the gyroscopic compasses used in naval practice. Reaction wheels were to be used to turn the satellite. But it turned out that common electric engines were not suitable for this purpose, thus it became necessary to work out a principally new system for an electric engine.

It is important to note that these solutions were offered because a real attitude control system was being worked out. This system was limited in mass and energy consumption, and this factor inspired the people who worked on the system to find new and unknown, at that time, ways, as using ordinary methods of control either made the system too heavy, or the energy consumption was inadmissibly large. The principal technical solutions, which served as a basis for working out an attitude control system for the OD satellite, are connected with the research work of Yevgeny Tokar.

The OD satellite has never been constructed. During the period of its construction, it became possible to increase the capacity of the launch vehicle, which allowed, in its turn the increase of the mass of the satellite launched. This new variant was later called "ship-satellite," and its first flight took place in 1960. The draft project of the OD satellite served as a basis for its control scheme, though some necessary changes were introduced (they were caused by the increase of satellite mass). But, before dwelling on this subject, it should be noted that a group of young scientists and engineers, who were working on the OD satellite project, was the only one in the U.S.S.R. capable of promptly working out an attitude control system. Thus, in 1957, this group was entrusted with a new urgent task.

This urgent task was to work out an attitude control system to photograph the far side of the Moon. Thus, starting from 1957, the work was carried on in two directions simultaneously, that is, they were connected both with the artificial satellite of the Earth and with a Moon vehicle.

The attitude control system fit for the Moon vehicle was much simpler than the one for an artificial satellite of the Earth. This was primarily accounted for by the fact that the process of attitude control was supposed to be rather short, not more than one hour, that is, the time which was needed for taking pictures. For the rest of the time, that is, the flying to the Moon and returning back to the Earth, an unorderly rotation of the vehicle around the center of mass was allowed. This simplicity resulted in the fact that the Moon project, which was started much later, was completed earlier than the first controlled satellite of the Earth was launched into space.

The little time needed for attitude control allowed not using complicated reaction wheels (which diminished the mass and energy consumption necessary for an attitude control system.). Besides, the requirements for the quality of attitude control were much simpler, as well. If for an artificial satellite it was necessary for all three axes (pitch, yaw, roll) to have necessary indications, in the Moon space vehicle it was sufficient to direct one optical axis of the camera on the Moon at the moment of taking pictures. Moreover, besides a sophisticated vehicle, which reacted to the infrared radiation of the Earth, and besides a gyroscopic device, which made it possible to locate an artificial satellite in the required position in relation to the orbit, in the Moon vehicle one could limit this to using common Sun and Moon sensors. In order to obtain forces of control, it was enough to provide a space vehicle, not with rocket fuel, but with a comparatively small amount of compressed nitrogen.

The attitude control system underwent thorough ground tests, and it proved to be highly effective before it was installed aboard the space vehicle. On the 7th of October 1959, an automatic interplanetary station, the Luna-3, took pictures of the rear side of the Moon from a distance of 6,500 kilometers. It was the beginning of an era for non-atmospheric astronomy and the first instance of attitude control of a space vehicle.

The results obtained convinced everybody that the founders of the system could conduct both theoretical research work and engineering work. The skyrocketing development of space devices, and the appearance of the new and more sophisticated space vehicles with more complicated requirements towards attitude control systems, demanded the corresponding reinforcement of the work in the field of control. It was impossible under the previous circumstances, thus in February of 1960, the whole group of specialists which was engaged in the sphere of practical problems of space control (about 100 people) was transferred to the organization headed by S. P. Korolev. Here the work was considerably expanded and reinforced. Besides, uniting under one roof the specialists working on the problems of control, with those who had worked out the space vehicle, proved to be rather fruitful. Any kind of experience was lacking at that time, and nearly all the things had to be done for the first time. It turned out that the movement control system of a space vehicle greatly influences its construction, thus the joint work headed by S. P. Korolev was a very timely event for the prompt and coordinated solution of all the problems.

Let us, however, come back to the history of creating the first attitude control systems for artificial satellites of the Earth. It has already been mentioned above that the OD project has never been realized. However, the ideas which originated in the process of working on the OD space vehicle were used to work out the corresponding systems for the "ships-satellite." They differed from the OD not only by the mass and the size, but they were to have a descent module. There were two models of these "ships-satellites," that is, fully automatic and piloted ones. The first model was to be used for photographing the Earth from space with the aim of reconnaissance, and the aim of the second model was to start piloted flights. As far as attitude control systems were concerned, they were practically identical for both models. Compared to the OD project, there was only one simplification made. The OD project contained two systems for getting the reactive momentum necessary to perform the turning of a vehicle. One of them consisted of three reaction wheels, the other produced reactive forces by thrusting compressed nitrogen from special nozzles. Both these systems were designed for working together. However, if using the gas thrust to obtain a reactive force was enough for the goals of control, the reactive wheels, though, did not possess this quality. Therefore, they had to be complimented by other systems, for example, by the system working on compressed nitrogen. The reason for using reaction wheels may be accounted for by the fact that, due to them, nitrogen expenditure was sharply decreased, thus, beginning from a certain flight duration (exceeding 10-15 days), their usage was becoming indispensable (provided the attitude control system is constantly operating). Working out a control system based on reaction wheels was planned to be the second phase of the project.

Two independent attitude control systems were installed on "ships-satellites." The first one was, in general, a replica of the one worked out for the OD satellite. Infrared sensors, gyroscopic devices for defining the position of orbital plane and, undoubtedly, rate gyros were used as sensors. This system made it possible to maintain a space vehicle in a required position, one of its geometric axes was oriented in the flight direction, and the other one was vertically oriented, that is, in such a position that the pictures of the Earth could be taken. The second system was extremely simple. The Sun served as the main orientation, and the axis of the jet engine was directed at it. A Sun sensor and a set of rate gyros guaranteed that the required attitude was achieved. It was quite evident that this system was suitable at least for landing. It was designed for the purpose of having an additional opportunity to land the space vehicle, provided the principal system had a failure in landing.

The first flight of the "ship-satellite" was held on May 1, 1960. At the initial phase of this flight, the infrared sensor stopped functioning, and an attempt at landing failed. During the second flight, on August 19 of the same year, the infrared sensor was broken again, but nevertheless the landing was successful as the "solar" system was used.

The thorough analysis of this phenomenon showed that the failures were the result of some physical phenomena, which the practice of engineering had never experienced before. It turned out that the process of friction in the vacuum of space occurs completely differently than on the Earth. As soon as this became clear, the methods of overcoming this unexpected obstacle were discovered. All this required time. However, the process of constructing piloted spacecraft of the Vostok type could not be delayed, especially in view of an unofficial competition with the "team" on the other side of the Atlantic Ocean. Therefore, it was decided to use a very simple, reliable, highly tested (in flights already) attitude control system, the main orientation for which was the Sun. It was quite sensible, as the first launches of piloted space vehicles mainly pursued medical and biological goals, hence, they did not need a constant attitude control. This became necessary only before descent to the Earth. The detailed history of constructing the Vostok spacecraft was described earlier.[3]

Summary

Prompt and effective development of work on creating attitude control systems for space vehicles in the U.S.S.R. was based on the theoretical research which was started in advance, two years before the opening of the era of space exploration and four years before such a system was used for the first time (1959).

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