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CONTROL PROGRAM FOR A MULTI-TYPE ELECTRIC PROPULSION SYSTEM FOR THE EARTH-MARS-EARTH-JUPITER MISSION

Abstract

In 2020, an international project "Democritos" of an interplanetary spacecraft with a nuclear power source and an electric propulsion system containing engines with various technical characteristics was published. The project aimed at conducting simultaneous testing of a nuclear power plant (Russia, the State Research Center of the Federal State Unitary Enterprise "Keldysh Center") and a set of twenty-two electric rocket engines from seven countries. The pilot goal of the mission was fly to Mars, return to Earth and fly to the Jupiter system to explore Europa.

This work aims at developing a methodology the optimal control program forming for spacecraft with such combined propulsion system. The minimum fuel consumption for a given flight duration is considered as an optimality criterion. We consider that all engines can be turned on and off separately, while the acceleration direction from the switched-on engines coincides. That is, it is assumed that the change in the direction of the thrust vector is due to the rotation of the spacecraft relative to the center of mass. In addition, it is assumed that the power of the power plant is sufficient for simultaneous operation of all engines switched on at a given time. Taking into account these technical limitations, the following statement of the problem is considered in this article. It is required to define a control program that ensures the fulfillment of the mission goal in a given time with a minimum mass of fuel consumed.

Using the Pontryagin's maximum principle, we obtained analytical expressions to determine the optimal on-off program and the acceleration direction for the engines. We carries out the detailed analysis of the control program and the required fuel mass dependence on the selected Earth -Mars flight duration. The using of a different electric engine type increases the spacecraft payload mass and reduces the operation duration of the engines with the highest specific impulse. This may be advantageous for fulfilling the restrictions on the engines' activation duration.

In conclusion, we carry out the full ballistic calculation of the Earth-Mars-Earth-Jupiter mission with the selection of the best launch date, determination of the required fuel reserves and the payload mass delivered to the Jupiter system.