SYNTHESIS OF MULTIPLE SMALL SPACE VECHICLE LAUNCH SYSTEM FOR DIFFERENT CONFIGURATION OF MAIN STAGE SEPARATION UNIT

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Modern hardware allows to build small satellites that can solve a wide range of tasks, previously available only for “large” satellites: the Earth remote sensing, exploration of the near Earth space, testing of new algorithms and subsystems for “large” satellites and even the space debris removal missions [1]. From a practical point of view most promising approach is the development of small spacecraft with a mass of about 400-700 kg, which can have large amount of on-board equipment and have a longer lifetime compared with satellites with smaller mass.

It is advisable to launch multiple satellites on a single launch vehicle to reduce the cost of launching a payload into orbit. The delivery to an orbit of cubesat satellites or satellites with mass of 100 kg can be carried out simultaneously with “large” payload [2]. To launch several satellites with mass 500 kg is necessary to develop special adapters for their joint entry into orbit and safe separation from the upper stage.

The safe separation of multiply small spacecraft from the upper stage is a complex problem. Wide range of the tasks must be solved:

1) developing requirements for orientation and stabilization of the upper stage;
2) building a safe separation timeline;
3) detailed analysis of the close-range relative motion of the spacecraft;
4) providing the accuracy of the separation devices;
5) analysis of the relative orbital motion of the satellites;
6) minimize the disturbances of the separation process to the attitude motion of the upper stage.

The requirements for the orientation and stabilization of upper stage should be formulated for the safe separation of the small satellites. These requirements depend on the location of satellites on the upper stage adapter and separation directions of the satellites. The well-known equations of the relative orbital motion [3,4] can be used to solve this problem. For near-circular orbits equations can be linearized and solved analytically [5]. Fig. 1 shows a possible scheme for separation of four and six satellites. For safe separation the optimal angle α_1 should be determined, which maximizes the difference between the projections of the separation velocities of the satellites on the direction of the orbital velocity of the upper stage - $\mathbf{V}_o$.

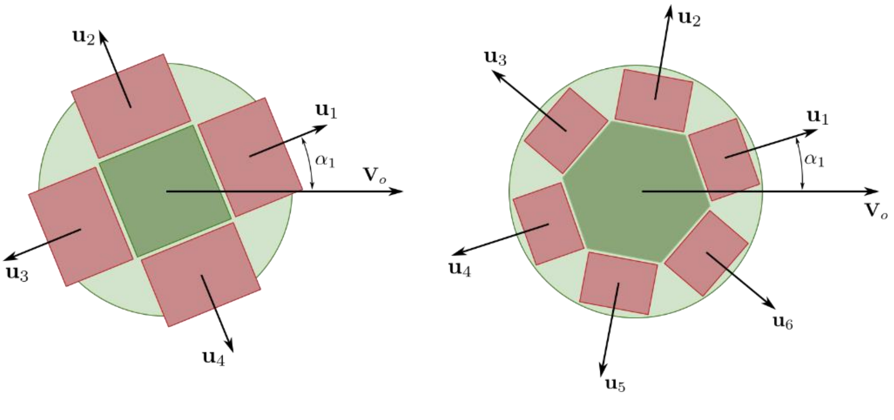

Fig. 1 – The separation of 4 and 6 satellites from upper stage

In case of impossibility of simultaneous separation of several spacecraft (when the separation directions are the same) a sequential separation timeline should be developed. Fig. 2 shows a scheme of multiple separation of small satellites using separation device - 3 installed on the upper stage adapter - 1 with the main payload – 2. One possible implementation of this scheme (Nanosatellite Launch Adapter System) is described in [5].

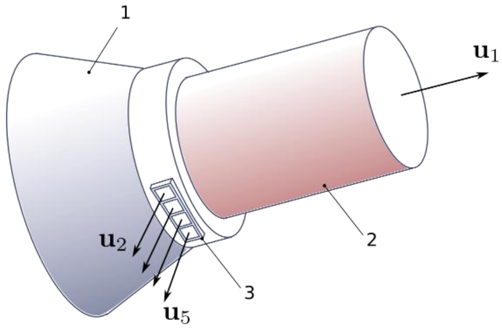

Fig. 2 – The separation of satellites in one direction

The most complex issues arise when the separation of several satellites in the different directions is not possible. One of this scheme is shown at fig. 6. Two satellites placed on the adapter within a payload region with maximum angle between the directions of the separation satellites. The axis of the upper stage can be rotated in the orbital plane before the separation to provide different angles between $\mathbf{u}_1$, $\mathbf{u}_2$ vectors and the vector of the orbital velocity of the upper stage $\mathbf{V}_o$. If the satellites have different masses then separation device can produce different velocities u_1, u_2 for safe relative motion of the satellites. Note that using the scheme that shown at fig. 6, can specify strict requirements to the timeline accuracy. Time difference between releasing the docking ring latches of two satellites can lead to the collision.

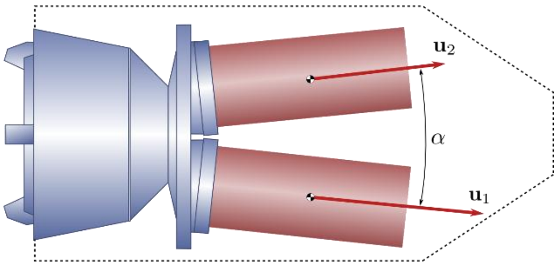

Fig. 3 – Separation of two satellites

Analysis of the separation process of several satellites is impossible without the use of an adequate mathematical model. Model of the considered system can be represented as a system of rigid bodies. To write the equations of motion the classical equations of motion of the center of mass of each satellite with Euler equations [6,7] and the kinematic equations written in Bryant angles [8] can be used. Taking into account the short duration of the separation process, effects of the spring pushers and the interface connector forces can be considered when building the equations of motion. The developed mathematical model must adequately describe all critical stages of the relative motion: the sliding of the satellite on the guiding pin and free motion under the action of the spring pushers.

The considered separation scheme (Fig. 3) imposes stringent requirements on the accuracy of the separation device. The variations of the spring pushers parameters (initial force, stroke and spring stiffness) are inevitable during the manufacturing process. These deviations can lead to undesirable perturbations of the attitude motion of the separated satellites. We also note that at the design stage the mass and the moments of inertia of the satellite also known with an uncertainty. The deviation of the center of mass position also can leads to the perturbation of the attitude motion of the satellite. For example, the separation of the “Aist” small satellite was performed with four spring pushers with total work 12 J. Maximum deviation of the center of mass from the longitudinal axis of the satellite does not exceed 6.5 mm. The maximum deviation of the initial force of the spring pusher from the average value does not exceed 10%. Mathematical analysis of separation process of the “Aist” small satellite showed that angular velocity of the satellite may be in the range from 0 to 7 degrees per second with average value about 2.7 degrees per second. According to the telemetry data from the two satellites launched in 2013 and 2014, angular velocities were 3.5 and 4 degrees per second, respectively.

To reduce the perturbation of the angular velocity of the satellite the selection of the pushers spring with similar characteristics can be used, as well as setting the parameters of the spring pushers to compensate the deviations of the measured position of the center of mass of a satellite.

It should also be noted that the separation of the small satellite using scheme Fig. 3, will require a late deployment of transformable structures of the satellite: solar array, antennas. Transformable structures usually open immediately after separation from the upper stage.

Thus, the safe separation of several satellites requires a detailed analysis of the relative motion of the satellites and the upper stage. Particular attention should be given to the accuracy of the separation devices and timeline of the separation process. To solve these complex tasks it is necessary to develop accurate model of the separation process.

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