UDC 621.454.2

O. V. PYLYPENKO, S. I. DOLHOPOLOV, O. D. NIKOLAYEV, N. V. KHORIAK

MATHEMATICAL SIMULATION OF THE START OF A MULTIENGINE LIQUID-PROPELLANT ROCKET PROPULSION SYSTEM

Institute of Technical Mechanics
of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine
15 Leshko-Popel St., Dnipro 49005, Ukraine; e-mail: dolmrut@gmail.com

The need for a lower cost and a shorter time of liquid-propellant rocket engine (LPRE) development and production often leads to the decision to use bundles of multiple engines developed individually in launch vehicles' sustainer liquid-propellant rocket propulsion systems (LPRPSs). This opens up prospects for providing a desired thrust by including the necessary number of engines in the bundle. Using sustainer LPRPSs with multiple engines causes additional problems due to the fact that the engines start nonsimultaneously. This may disrupt the operation of engines that start with a delay or produce an overturning moment when rocket detaches from the launcher. The aim of this paper is to study dymanic processes at the start of a multiengine LPRPS with four LPREs with oxidizing generator gas afterburning with account for the possibility of the engines starting nonsimultaneously. The paper presents a mathematical model of the start of the multiengine LPRPS under consideration and the results of calculations by the model. It is shown that, as distinct from all the engines starting simultaneously, their nonsimultaneous start may result in deep prolonged dips in the propellant flow rate accompanied by deep prolonged dips in the pressure at the engine inlets. This may cause cavitation stall in one or more pumps, which may disrupt the operation of the whole of the propulsion system and result in an emergency. The results of mathematical simulation of the four-engine LPRPS start show that the character and degree of the effect of possible engine start delays on transients depend on a variety of factors governed by the LPRPS composition and dynamic performance, start conditions, etc. Because of this, for multiengine LPRPS start reliability to be improved, in each particular case, i.e., for each new or upgraded LPRPS and launch vehicle, start transients should be studied numerically with account for a nonsimultaneous start of the LPRPS engines.

1. Shevyakov A. A., Kalnin V. M., Naumenkova M. V., Dyatlov V. G. Theory of Rocket Engine Automatic Control. Moscow: Mashinostroyeniye, 1978. 288 pp. (in Russian).

2. Belyaev E. N., Chervakov V. V. Mathematical Simulation of Liquid-Propellant Rocket Engines. Moscow: MAI-PRINT, 2009. 280 pp. (in Russian).

3. Liu Wei, Chen Liping, Xie Gang, Ding Ji, Zhang Haiming, Yang Hao Modeling and Simulation of Liquid Propellant Rocket Engine Transient Performance Using Modelica. Proc. of the 11th Int. Modelica Conf., 2015, Sept. 21-23, Versailles. France.   p. 485-490. URL: www.ep.liu.se/ecp/118/052/ecp15118485.pdf of Jul. 13, 2017

4. Di Matteo, Fr., De Rosa, M., Onofri, M. Start-Up Transient Simulation of a Liquid Rocket Engine. AIAA 2011-6032 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit (31 July - 03 August 2011), San Diego, California. 15 pp. URL: www.enu.kz/repository/2011/AIAA-2011-6032.pdf. https://doi.org/10.2514/6.2011-6032

5. Belov G. V. Simulation of multicomponent heterogeneous system equilibrium states, Matematicheskoe Modelirovanie. 2005. V. 17, No. 2. Pp. 81-91. (in Russian).

6. Lebedinsky E. V., Zaitsev B. V., Sobolev A. A. Multilayer mathematical simulation of a flow regulator for a liquid-propellant rocket engine. Website of the State Scientific Center "Keldysh Research Center." 2011. P. 10. (in Russian).

7. Lebedinsky E. V., Kalmykov G. P., Mosolov S. V. et al,; Koroteev A. S. (Ed.). Working Processes in a Liquid-Propellant Rocket Engine and Simulation Thereof. Moscow: Mashinostroyeniye, 2008. 512 pp. (in Russian).

8. Pilipenko V. V., Zadonsev V. V., Natanzon M. S. Cavitation Oscillations and Hydrosystem Dynamics. Moscow: Mashinostroyeniye, 1977. 352 pp. (in Russian).

9. Pylypenko O. V., Prokopchuk A. A., Dolgopolov S. I., Pisarenko V. Yu., Kovalenko V. N., Nikolaev A. D., Khoryak, N. V. Pequliarities of mathematical modeling of low-frequency dynamics of the staged liquid rocket sustainer engines at its startup Space Sci.&Technol. 2017. V. 23, No, 5. Pp. 3-12. (in Russian).
https://doi.org/10.15407/knit2017.05.003

10. Degtyarev A. V. Space Technology. Problems and Prospects. Dnipropetrovsk: ART-PRESS, 2014. 420 pp. (in Russian).

11. Pylypenko O. V., Prokopchuk A. A., Dolgopolov S. I., Khoryak N. V., Nikolaev A. D., Pisarenko V. Yu.. Kovalenko V. N. Mathematical simulation and stability analysis of low-frequency processes in a sustainer liquid-propellant rocket engine with generator gas afterburning. Vestnik Dvigatelestroyeniya. 2017. No. 2. Pp. 34-42. (in Russian).

12. Khoriak N. V., Dolhopolov S. I. Features of mathematical simulation of gas path dynamics in the problem of the stability of low-frequency processes in liquid-propellant rocket engines. Teh. Meh. 2017. No. 3. Pp. 30-44. (in Russian).
https://doi.org/10.15407/itm2017.03.030

13. Pylypenko O. V., Khoriak N. V., Dolhopolov S. I., Nikolayev O. D. Mathematical simulation of dynamic processes in hydraulic and gas paths at the start of a liquid-propellant rocket engine with generator gas after-burning. Teh. Meh. 2019. No. 4. Pp. 5-20. (in Russian).
https://doi.org/10.15407/itm2019.04.005
https://doi.org/10.15407/itm2019.04.005

14. Pilipenko V. V., Dorosh N. L., Manko I. K. Experimental study of vapor condensation during the injection of an oxygen gas jet into a liquid oxygen flow. Teh. Meh. 1993. No. 2. Pp. 77-80. (in Russian).

15. Dolgopolov S. I., Nikolaev A. D. Mathematical modelling low-frequency dynamics of flow controller at various amplitudes of harmonic disturbance. Teh. Meh. 2017. No. 1. Pp. 15-25. (in Russian).
https://doi.org/10.15407/itm2017.01.015

16. Pilipenko V. V., Dolgopolov S. I. Experiment-calculation determination of the coefficients of an equation of cavity dynamics in inducer-equipped centrifugal pumps of various standard sizes. Teh. Meh. 1998. No. 8. Pp. 50-56. (in Russian).

17. Dolgopolov S. I. Hydrodynamic model of cavitation oscillation for modelling dynamic processes within pump systems at high cavitation number. Teh. Meh. 2017. No. 2. Pp. 12-19. (in Russian).
https://doi.org/10.15407/itm2017.02.012

18. Dolgopolov S. I., Zavoloka A. N., Nikoilaev A. D., Sviridenko N. F., Smolensky D. E. Parametric determination of hydrodynamic processes in feed system of space stage in stopping and starting the cruise engine. Teh. Meh. 2015. No. 2. Pp. 23-36. (in Russian).

19. Sobol I. M., Statnikov I. M. Choice of Optimal Parameters in Multicriteria Problems. Moscow: Nauka. 1981. 110 pp. (in Russian).

20. Pilipenko V. V., Dolgopolov S. I. Mathematical simulation of the start of the RD-8 liquid-propellant rocket engine with account for cavitation in the pumps. Teh. Meh. 2003. No. 2. Pp. 18-24. (in Russian).