Development of technology of creating a system for diagnosis and emergency protection of liquid rocket engines

© T.Ch. Kolbaya[1], S.M. Pasmurnov[2], D.Yu. Yakush[1]

[1]JSC "Konstruktorskoe Buro Khimavtomatiki", Voronezh, 394006, Russia
[2]Voronezh State Technical University, Voronezh, 394026, Russia

The article deals with the diagnostics and emergency protection system (DEPS) of liquid rocket engines (LRE) and the challenges the system faces. First, we formulate the main directions of DEPS improvement and show the structure of the system, including not only the software and hardware which directly implement the fault detection and emergency protection functions, but also the system's ancillary elements complex, making possible its setting and adjustment. Next, we propose DEPS test set-up for both the autonomous system testing, and complex testing with the protection object and the top-level control system. Moreover, we present the procedure that enables debugging of the most part of DEPS software without reference to its hardware. Finally, we evaluate the technology development results.

Keywords: *diagnostics, emergency protection and control system, software, diagnostic algorithm, liquid rocket engine*.

REFERENCES

[1] Glikman B.F. *Avtomaticheskoe regulirovanie zhidkostnykh raketnykh dvigateley* [Automatic control of liquid rocket engines]. Moscow, Mashinostroenie Publ., 1989, 296 p.

[2] Moiseev N.F., ed. *Ispytatelnye kompleksy i eksperimentalnaya otrabotka zhidkostnykh raketnykh dvigateley* [Test systems and experimental testing of liquid rocket engines]. Moscow, Mashinostroenie Publ., Mashinostroenie–Polet Publ., 2012, 368 p.

[3] Kolomentsev A.I., Kraev M.V., Nazarov V.P. *Ispytanie i obespechenie nadezhnosti raketnykh dvigateley* [Testing and ensuring the reliability of rocket engines]. Krasnoyarsk, SGAU-MAI Publ., 2006, 336 p.

[4] Golovin Yu.M. *Fundamentalnye i prikladnye problemy kosmonavtiki — Fundamental and Applied Problems of Astronautics*, 2002, no. 9, pp. 34–38.

[5] Golovin Yu.M., Gubertov A.M., Yakushin N.I. *Rossiiskiy kosmos — Russian Space*, 2002, no. 2, pp. 9–12.

[6] Martirosov D.S., Sinkov S.A. *Trudy NPO Energomash im. akademika V.P. Glushko — Proceedings of NPO Energomash named after academician V.P. Glushko*, 2005, no. 23, pp. 151–160.

[7] Pinchuk V.A., Gribakin V.A., Boldyrev K.B., Perfiliev A.S. *Mekhatronika, avtomatizatsiya, upravlenie. Prilozhenie — Mechatronics, Automation, Control. Appendix*, 2007, no. 11, pp. 17–23.

[8] Teidzhvani G., Makvey G., Langford L. Diagnostirovanie kislorodno-uglevodorodnykh raketnykh dvigateley: razvitie analiticheskikh i eksperimentalnykh metodov [Diagnosing oxygen-hydrocarbon rocket engines: the development of analytical and experimental methods]. *41-ya obyedinennaya konferentsiya AIAA/ASME/SAE/ASEE po dvigatelyam i ikh demonstratsii* [The 41th Joint Conference AIAA/ASME/SAE/ASEE on engines and their demonstration], 2006, AIAA 2006–4407.

[9] Roemer M. Dzh., Kasprzhinski G.Dzh., Malloy D. Podkhod k sozdaniyu podstraivaemoy sistemy diagnostiki defektov dvigateley i stendov dlya ikh ispytaniy [The approach to creating the adjustable diagnostic system of engine defects and test bench for them]. *38-ya sovmestnaya konferentsiya AIAA/ASME/SAE/ASEE po dvigatelyam i ikh demonstratsii* [The 38th Joint Conference AIAA/ASME/SAE/ASEE on engines and their demonstration], 2002, AIAA 2002–4307.

[10] Barikharadan S. Otsenka sistem kontrolya realnogo vremeni dlya dvigatelnykh i energeticheskikh sistem [Evaluation of real time control systems, for propulsion and power systems]. *41-ya obyedinennaya konferentsiya AIAA/ASME/SAE/ASEE po dvigatelyam i ikh demonstratsii* [The 41th Joint Conference AIAA/ASME/SAE/ASEE on engines and their demonstration], 2005, AIAA 2005–3716.

[11] Pizzo D.T., Adib R.M. Veroyatnostnyy analiz vidov i mekhanizmov otkaza i vozdeystviy [Probabilistic analysis of the failure types and mechanisms and impacts]. *38-ya sovmestnaya konferentsiya AIAA/ASME/SAE/ASEE po dvigatelyam i ikh demonstratsii* [The 38th Joint Conference AIAA/ASME/SAE/ASEE on engines and their demonstration], 2002, AIAA 2002–4043.

[12] Bondar A.I., Pasmurnov S.M., Yakush D.Yu. Programmno-matematicheskoe obespechenie sistemy avariynoy zashchity i upravleniya ZhRD i protsedura ego testirovaniya [Software and mathematical support of the emergency protection and LRE (liquid rocket engine) control system and the procedure of its testing]. *Nauka i tekhnologii: Sbornik nauchnykh trudov* [Science and Technology. Collection of scientific papers]. Moscow, RAS Publ., 2015, vol. 5, p. 137.

[13] Aguilar R., Liu Ch., Santi L.M., Shein Souers T. Imitatsiya v realnom vremeni dlya proverki i utverzhdeniya diagnosticheskikh i prognosticheskikh algoritmov [Real time simulation for verification and validation of diagnostic and prognostic algorithms]. *41-ya obyedinennaya konferentsiya AIAA/ASME/SAE/ASEE po dvigatelyam i ikh demonstratsii* [The 41th Joint Conference AIAA/ASME/ SAE/ASEE on engines and their demonstration], 2005, AIAA 2005–3717.

[14] Khuang B., Li Ks., Li M., Bernshtein Dzh., Shmidt K. Profil otkaza programmnogo obespecheniya, vyzvannyy otkazom apparatnykh sredstv [Viewing software failure caused by hardware failure]. *41-ya obyedinennaya konferentsiya AIAA/ASME/SAE/ASEE po dvigatelyam i ikh demonstratsii* [The 41th Joint Conference AIAA/ASME/SAE/ASEE on engines and their demonstration], 2005, AIAA 2005–4483.

[15] Tansel I. N., Chen P., Yenilmez A., Lindsei Kh., Viu B. Razrabotka algoritma pryamoy i obratnoy otsenki s ispolzovaniem neyronnoy seti [Development of forward and reverse estimation algorithm using neural network]. *41-ya obyedinennaya konferentsiya AIAA/ASME/SAE/ASEE po dvigatelyam i ikh demonstratsii* [The 41th Joint Conference AIAA/ASME/SAE/ASEE on engines and their demonstration], 2005, AIAA 2005–4527.

[16] Souers Sh.T., Santi M.L., Bikford R.L. Otsenka proizvoditelnosti sistemy proverki dostovernosti dannykh [Evaluation of data validation system performance]. *41-ya obyedinennaya konferentsiya AIAA/ASME/SAE/ASEE po dvigatelyam i ikh demonstratsii* [The 41th Joint Conference AIAA/ASME/SAE/ASEE on engines and their demonstration]. 2005, AIAA 2005–4486.

[17] Bikford R.L., Malloy D. Osuschestvlenie ustanovki sistemy diagnostiki dvigatelya turbiny pri nazemnykh ispytaniyakh v realnom vremeni [Implementation of the turbine engine diagnostics system installation during

ground tests in real time]. *41-ya obyedinennaya konferentsiya AIAA/ASME/SAE/ASEE po dvigatelyam i ikh demonstratsii* [The 41th Joint Conference AIAA/ASME/SAE/ASEE on engines and their demonstration], 2005, AIAA 2005–4334.

[18] Bondar A.I., Kolbaya T.Ch., Shostak A.A., Yakush D.Yu. Tekhnologiya avtomatizatsii razrabotki sistem diagnostirovaniya, avariynoy zaschity i upravleniya zhidkostnykh raketnykh dvigateley [Automation technology of developing liquid rocket engines diagnostics, emergency protection and control systems]. *Raketno-kosmicheskie dvigatelnye ustanovki: sb. materialov Vserossiyskoy nauchno-tekhnicheskoy konferentsii* [Rocket-space propulsion systems: col. materials of All-Russian scientific and technical conference]. Moscow, IPC MRSU Publ., 2013, pp. 78–80.

Kolbaya T.Ch. (b. 1981) graduated from Voronezh State Technology Academy in 2004. Cand. Sci. (Eng.). Project manager of JSC "Konstruktorskoe Buro Khimavtomatiky". Author of over 30 scientific works in the field of mathematical modeling of compressible fluid, diagnostics of actuators, developing diagnostics, emergency protection and control systems of liquid rocket engines and power plants. e-mail: timur2607@rambler.ru

Pasmurnov S.M. (b. 1952) graduated from Voronezh Polytechnic Institute in 1977. Cand. Sci. (Eng.), Professor, the Dean of the Faculty of Information Technologies and Computer Security, Voronezh State Technical University. Author of about150 scientific and methodological works in the field of software for analysis and synthesis of design solutions in automated systems. e-mail: smpas-murnov@mail.ru

Yakush D.Yu. (b. 1969) graduated from Voronezh Polytechnic Institute in 1992. Leading designer of JSC "Konstruktorskoe Buro Khimavtomatiky". Author of over 10 scientific works in the field of liquid rocket engines emergency protection systems development. Post-graduate Student of the Department of Computer-aided Design and Information Systems, Voronezh State Technical University. e-mail: duyakush@mail.ru