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DEVELOPMENT OF THE HELICOPTER TURBOSHAFTED ENGINE REGULATOR

The subject of research was the development of the RDC-450M-117V – the TV3-117VMA-SBM1V digital engine regulator – based on the RDC-450M previously created at the enterprise for the AI-450M engine, considering differences in engine characteristics and exploitation conditions. *The work purpose* was to develop RDC-450M-117V based on information about aircraft engine characteristics, including refinement of its mathematical model based on experimental data, taking into account the exploitation condition difference. *The tasks* faced by the developers were to determine the optimal regulator structure in view of exploitation conditions, refine the mathematical model of the engine, and study the characteristics of the pump-regulator, to select the optimal processing form for the signal of rotation sensors for torque measurement. *The methods* that were applied were experimental engine and pump-regulator characteristics study on the stands of JSC "Element", JSC "Motor Sich", and on pump-regulator manufacturer's stands; processing of experimental data using numerical simulation with subsequent statistical analysis. The rotation sensors signals experimental data (waveforms) were studied using a quantitative analysis method. *The results.* Design and software documentation was developed considering the requirements of international standards DO-254 and DO-178C, and a prototype of the regulator new modification was made. The engine mathematical model was refined, on the basis of which the stand-imitator of aircraft engines was finalized for a new type of engine. An adaptive algorithm for controlling the pump-regulator was developed, which made it possible to ensure stable maintenance of fuel consumption, despite the unstable operation of the pump-regulator. Using a quantitative analysis of the torque sensor signal waveforms, characteristic points were found that ensure the choice of the optimal level of comparison (measurement). The pilot regulator prototype passed tests including electromagnetic compatibility and lightning resistance in specialized laboratories in Ukraine. The regulator was tested as part of the engine at the Motor Sich JSC stands and as part of a helicopter at the foreign customer site, including the first demonstration flight. *The scientific novelty* of the obtained results are: the clarified engine TV3-117VMA-SBM1V mathematical model was formed and implemented in a stand-imitator; the adaptive algorithm for controlling the pump-regulator was formed and allowed to provide stable fuel consumption maintenance, despite the pump-regulator unstable operation; and the optimal processing form for the signal of rotation sensors for measuring torque was selected. *Practical significance.* A new engine regulator was developed and tested, and it provided the first helicopter demonstration flight.

Keywords: aviation equipment components; engine regulator; mathematical model.

Introduction

The aircraft engines digital regulators developing and serially produced by JSC Element are the main elements of automatic control systems for a number of engines developed by SE Ivchenko–Progress and JSC Motor Sich. These are such engines as for example the AI-450 (Mi-2M helicopter and Mi-2MSB), AI-450V (Mi-2MSB-V helicopter), AI-450S (DART-450 aircraft), MS-500V-02S, as well as an unmanned aerial vehicle engine [1, 2].

The experience accumulated over more than two decades in the development, testing and manufacture of regulators allows Element JSC, a certified developer and manufacturer of aircraft components, to solve increasingly complex problems of creating new modifica-

tions of digital engine regulators – RDC blocks. These are both purely technical tasks, as well as organizational and methodological issues, due, among other things, to the requirements of foreign customers, cooperation with which has been expanding in recent years. Thus, during the development of the RDC-450M-117V regulator for the TV3-117VMA-SBM1V engine (which is currently being ended) at the request of a foreign customer (helicopter developer) in addition to the previously mandatory procedures, regulated by Qualification Requirements DO-178, development procedures were introduced (more precisely, the order of their documentation) according to DO-254 "Design assurance guidance for airborne electronic hardware". This DO-254 implementation is reflected in [3]. The purely technical side of this development is covered in this article.

1. Formulation of the problem

The development of the RDC-450M-117V regulator, based on the previously tested the development of previous modifications of the RDC-450M regulators family and the design, circuitry, software and technological solutions that confirmed the effectiveness, required to take into account:

- differences in the characteristics of external influencing factors, especially more stringent requirements in terms of electromagnetic compatibility, allowable power failures and lightning resistance;

- the need to refine the mathematical model of the engine and study the characteristics of the pump-regulator, which required a series of tests as part of the engine to obtain initial data for integration into the stand-imitator [4] and algorithms control refinement;

- the need to use an adaptive control algorithm for the pump-regulator (which was revealed by the results of a study of its characteristics);

- requirements for a significant expansion of the memory capacity of the parameter recorder, which is impossible without changing its hardware base, and in addition led to the adoption of measures for some reorganization of data reading;

- new concerning what all previous models of the RDC-450M family worked with (although it has been known for a long time), a method for measuring torque using rotation sensors.

2. Results

The appearance of the RDC-450M-117V prototype manufactured and passed to date series of tests (including electromagnetic compatibility tests, as well as tests as part of the engine and as part of the helicopter) is shown in Figure 1. The regulator body design is similar to that of the base model [1], but slightly differs in proportions. The modular structure and basic technological solutions have been preserved. However, the element base has undergone certain changes – partly due to the constant updating of proposals on the market for components of electrical radio elements, but mainly due to changes in the requirements for resistance to external influencing factors.

So, for example, in terms of the indirect impact of lightning, according to section 22.0 of the DO-160G Qualification Requirements, the category A3J3L3 is set, which, among other things, provides for verification by the contact input method with a test level of 600 V / 24 A, while for the previous blocks the test level was normalized 250V/10A.

In specialized laboratories in Kharkov, a prototype of the RDC-450M-117V regulator was tested for com-

pliance with the requirements for:

- the regulator as a receiver of electricity – Sections 16.0, 17.0 and 18.0 of DO-160G;

- electromagnetic compatibility – Sections 19.0, 20.0 and 21.0 of DO-160G;

- susceptibility to electrostatic discharge – Section 25.0 DO-160G;

- indirect effects of lightning – section 22.0 of DO-160G.

Since the characteristics of the electric cable have a significant impact on the resistance of the product to the above effects, to fully reproduce the real operating conditions, the tests were carried out with the original helicopter cable received from a foreign customer. It should be noted that the tests revealed shortcomings in the shielding of the cable.



Fig. 1. RDC-450M-117V appearance

As for the regulator, incomplete compliance with the requirements of sections 20.0 (at some frequencies of the required range, the susceptibility of the RDC-450M-117V regulator exceeded the permissible level) and 22.0 DO-160G (exposure to the contact input by the above mentioned level of 600 V / 24 A damaged some elements of the input circuits). For the rest of the tests regulator passed successfully.

To date, measures have been worked out to eliminate the identified inconsistencies, the necessary regulator circuit adjustments have been determined and, based on the results of the search, new components of the electroradioelements have been selected, namely:

- elements for finalizing input circuits, resistant to contact input 600 V / 24 A, the installation of which, instead of the previously used ones, will provide the required level of lightning resistance according to section 22.0 of DO-160G;

- electrical connectors with integrated filters that provide interference suppression at frequencies that turned out to be critical for the regulator and at the same

time are resistant to other specified influences, including testing with a 600 V / 24 A contact input, which will allow to achieve full compliance with the requirements for radio frequency susceptibility according to section 20.0 DO-160G.

When checking the fulfillment by the regulator of the main functions for its intended purpose, Element JSC already traditionally uses an aircraft engine stand-imitator [4]. Verification of the mathematical model built into the stand is carried out by comparing the test results of the regulator on the stand-imitator and as part of the engine on the stand for engine tests. According to the test results, it turned out that the mathematical model previously provided by the engine developer required the adjustment of several essential details. Thus, the throttle characteristics of the model were refined, and the model dynamic block was refined in terms of calculating the free turbine rotation speed n_{st} , taking into account non-linear and non-stationary relationships with the turbocharger rotation speed n_{tk} . The dynamic model's adequacy was assessed both qualitatively (the form and nature of transient processes, inflection points) and quantitatively (the time of transient processes, the magnitude of overshoots and dips, etc.).

The pump-regulator characteristics study (carried out at the site of the pump developer and at the stand of Motor Sich JSC), as well as the interaction of the pump

with the RDC-450M-117V regulator, revealed that the commonly used proportional-integral-derivative (PID) controller is not the optimal solution, because of the difference between pumps characteristics and the nominal. Additionally, characteristics spread from specimen to specimen (as illustrated in Figure 2) exceeded an acceptable level, including:

- the dead zone was either noticeably wider than the nominal one, or turned out to be asymmetric concerning the zero value of the control current (shifted) - Figure 2;

- the change rate of the damper opening angle at a constant current value changed in time.

This situation forced the use of an adaptive algorithm for controlling the pump-regulator. The algorithm consists in the fact that during the transition between steady-state modes, the control current is formed taking into account not only the deviation of the present value of the fuel consumption from the set value, but also taking into account the tracked dynamics of the change in the regulated flow.

The method of torque measurement using rotation sensors chosen by the engine developer required changes to the corresponding measuring channel of the regulator. All previous modifications of the RDC-450M “dealt” with a relatively simple measurement of the DC voltage value from the P_{ikm} sensor.

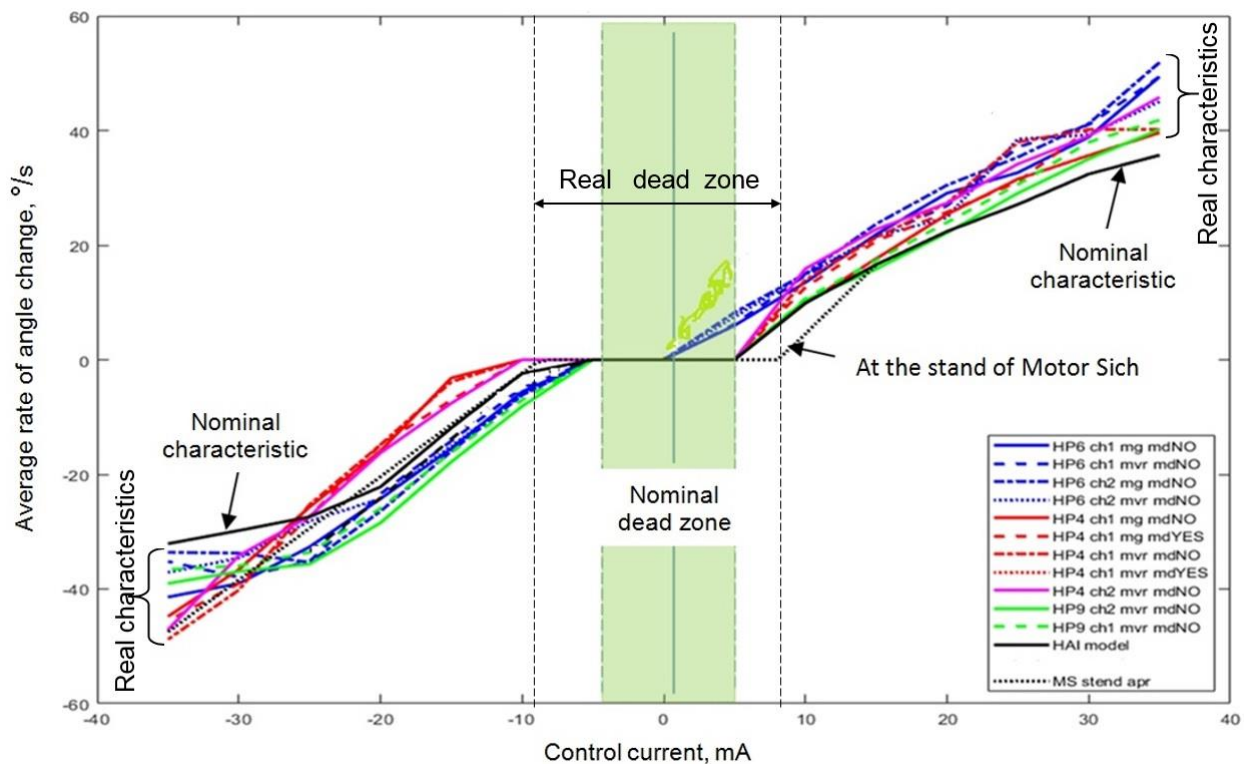


Fig. 2. Comparison of experimentally obtained characteristics three two-channel pump-regulators with a nominal characteristic

But the RDC-450M-117V regulator needs to determine the "distortion" of the quasi-sinusoid period (phase shift) as an informative signal, reflecting the angle of shaft twisting, against the background of a change in its period (and amplitude), proportional to the speed of rotation of the shaft. This, firstly, meant much more stringent requirements for the polling frequency, and secondly, it required additional experimental data to select measurement points on the sinusoid, that is, to determine the front of the sinusoid and the signal level concerning the amplitude (comparison level).

The comparison level search was performed by points for which the second derivative of the voltage concerning time is equal to zero. As for the front choice, when studying the signal received from the torque meter, it turned out that due to the specific design of the inductors kinematically connected to the loaded and unloaded parts of the output shaft of the free turbine (measuring shaft), the leading edge of the quasi-sinusoid undergoes a noticeable distortion, in contrast to the stress decline section. The graph of Figure 3 illustrates the above, in which numbers 1 and 2 conventionally denote the pulses from the two inductors mentioned above and mark the points with a zero second derivative of the voltage versus time function.

Based on the results of the analysis, the level of 0.55 from the current value of the amplitude in the descending sections of the curve was selected as providing the best result.

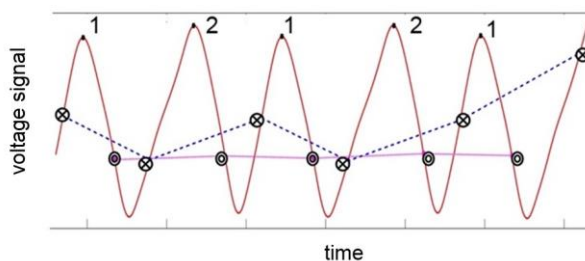


Fig. 3. Illustration of the selection of the level and the front of comparison (measurement) points

The built-in registrar of the RDC-450M-117V parameters has a significantly larger amount of memory compared to previous modifications of the RDC-450M family of regulators, which is achieved through the use of a new element base. This, in its turn, led to measures to increase the speed of reading data from the recorder, in particular, replacing the ARINC 429 interface with RS-422 in the technological data transmission channel (ARINC 429 is retained for the channels of exchange with onboard devices).

In addition, an algorithm has been developed for automatically selecting the optimal value (out of several preset ones) for the data exchange rate between the

KPTO-117 maintenance kit and the RDC-450M-117V regulator. The automatic selection depends on the length of the connecting cable, which makes it possible to avoid unjustified increase read time when using a relatively short cable and prevent data loss if you need to use a long one.

To date, a prototype regulator has been tested both as part of the engine at the stands of Motor Sich JSC, and as part of a helicopter at the site of a foreign customer. In general, the test results, including the first demonstration flight, are positive. The necessary adjustments were determined both for the requirements of the technical specifications, and for the design and software documentation of the regulator.

Conclusion

1. JSC "Element" developed (taking into account the requirements of DO-254 and DO-178C) working design documentation and the necessary software, a prototype of the RDC-450M-117V digital regulator for the TV3-117VMA-SBM1V engine developed JSC "Motor Sich". During the development process, the mathematical model of the engine was refined and the engine stand-imitator was improved, which provides testing of the regulator at the site of Element JSC.

2. A prototype regulator has passed a series of tests:

- at the enterprise-developer – for compliance with the requirements for the performance of functions for their intended purpose, as well as for resistance to mechanical and climatic external influencing factors;

- in specialized laboratories in Kharkov – for compliance with the requirements for electromagnetic compatibility, lightning resistance and as a receiver of electricity by Qualification requirements DO-160G;

- in JSC "Motor Sich" – at specialized stands as part of the engine;

- at the site of the helicopter developer (foreign customer) – tests as part of a helicopter, including the first demonstration flight.

3. Currently, the adjustment of requirements, design and software documentation and the completion of the sample based on the test results are being completed.

Authors' contributions: problem statement – **Gennadii Ranchenko**; information sources review – **Anna Buryachenko**; development of basic hardware solutions – **Dmitriy Burunov**; software – **Vsevolod Danilov**; experimental studies and analysis of their results – **Viacheslav Grudinkin, Anna Buryachenko**.

All authors have read and agreed with the published version of the manuscript.

References

1. Ranchenko, G. S., Burjachenko A. G., Grudinkin, V. M. & Danilov, V. V. *Bazovoye ispolneniye regulatora aviadvigatelya i yego modifikatsii* [Basic model of the aircraft engine regulator and its modifications]. *Aviacijno-kosmicna tehnika i tehnologia – Aerospace technic and technology*, 2020, no. 8 (168), pp. 160-165. DOI: 10.32620/akt.2020.8.21.
2. Buryachenko, A. G., Ranchenko, G. S. & Taranishin A. O. *Regulyator dlya dvigatelya MS-500 – razrabotka, ispytaniya, sertifikatsiya* [Regulator for engine MS-500 – development, testing, certification]. *Aviacijno-kosmicna tehnika i tehnologia – Aerospace technic and technology*, 2021, no. 4sup2 (174), pp. 87-92. DOI: 10.32620/akt.2021.4sup2.11.
3. Ranchenko, G. S., Buryachenko, A. G., Hrudinkin, V. M. *Vnedreniye DO-254 v protsess razrabotki regulyatorov aviadvigateley* [Implementation DO-254 into the Development of Aircraft Engine Controllers]. *Aviacijno-kosmicna tehnika i tehnologia – Aerospace technic and technology*, 2022, no. 4sup1 (181), pp. 107-112. DOI: 10.32620/akt.2022.4sup1.14.
4. Buryachenko, A. G., Burunov, D. S., Grudinkin, V. M. & Taranishin, A. O. *Stend-imitator aviadvigatelya kak universal'noye sredstvo obespecheniya razrabotki i ispytaniy regulyatorov* [Stand imitator of the engine as a universal means of ensuring the development and testing of regulators]. *Aviacijno-kosmicna tehnika i tehnologia – Aerospace technic and technology*, 2020, no. 7 (167), pp. 83-88. DOI: 10.32620/akt.2020.7.12.

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РОЗРОБКА РЕГУЛЯТОРА ВЕРТОЛІТНОГО ТУРБОВАЛЬНОГО ДВИГУНА

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Предметом дослідження була розробка цифрового регулятора двигуна РДЦ-450М-117В – ТВ3-117ВМА-СБМ1В – на базі раніше створеного на підприємстві РДЦ-450М для двигуна АІ-450М з урахуванням відмінностей у характеристики двигуна та умов експлуатації. **Метою** роботи була розробка РДЦ-450М-117В на основі інформації про характеристики авіаційного двигуна, включаючи уточнення його математичної моделі на основі експериментальних даних з урахуванням різниці умов експлуатації. **Завдання**, які стояли перед розробниками, полягали у визначенні оптимальної структури регулятора з урахуванням умов експлуатації, уточненні математичної моделі двигуна та дослідженні характеристик насоса-регулятора, виборі оптимальної форми обробки сигналу датчиків обертання для вимірювання крутного моменту. **Методи**, що застосовані: експериментальне дослідження характеристик двигуна та насос-регулятора на стендах АТ «Елемент», АТ «Мотор Січ» та на стендах виробників насос-регулятора; обробка експериментальних даних із застосуванням метода чисельного моделювання з подальшим статистичним аналізом. Експериментальні дані (сигнали) датчиків обертання досліджувалися методом кількісного аналізу. **Результати**. Розроблено конструкторську та програмну документацію з урахуванням вимог міжнародних стандартів DO-254 та DO-178С, виготовлено дослідний зразок регулятора нової модифікації. Уточнено математичну модель двигуна, на основі якої розроблено стенд-імітатор авіаційних двигунів для нового типу двигуна. Сформовано адаптивний алгоритм керування насосом-регулятором, який дозволив забезпечити стабільне підтримання витрати палива, незважаючи на нестабільну роботу насоса-регулятора. За допомогою кількісного аналізу осцилограм сигналу датчика крутного моменту знайдено характерні точки, що забезпечують вибір оптимального рівня порівняння (вимірювання). Дослідний зразок регулятора пройшов випробування, в тому числі на електромагнітну сумісність та стійкість до дії блискавки у спеціалізованих лабораторіях України. На даний момент регулятор пройшов випробування в складі двигуна на стендах АТ «Мотор Січ» і в складі гелікоптера на майданчику іноземного замовника, в тому числі в першому демонстраційному польоті. **Наукова новизна** отриманих результатів полягає у тому, що: сформовано та реалізовано в стенді-імітаторі уточнену математичну модель двигуна ТВ3-117ВМА-СБМ1В; сформовано адаптивний алгоритм керування насосом-регулятором, що дозволяє забезпечити стабільну підтримку витрати палива, незважаючи на нестабільну роботу насоса-регулятора; обрано оптимальну форму обробки сигналу датчиків обертання для вимірювання крутного моменту. Практичне значення. Розроблено, випробувано новий регулятор двигуна, який забезпечив перший демонстраційний політ гелікоптера.

Ключові слова: комплектуючі вироби авіаційної техніки; регулятор двигуна; математична модель.

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