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THE OPERATIONAL TECHNIQUE FOR THE MAJOR COMPONENTS OF AFTERBURNING TURBOFAN ENGINE ROTORS

The operational technique for the major components of the fighter aircraft engine rotors has been introduced proceeding from the real conditions of their cyclic loading in each flight or ground test and a priori information on their previous operation. It has been confirmed that the obtained technical solutions not only conform to the current methods of accounting for the depletion of the cycle life of the Afterburning Turbofan Engine (ATE), but also introduce additional opportunities to consider individual characteristics and conditions of their cyclic loading throughout the overall operating time. A method for estimating the depletion of the cycle life in accordance with the Total Accumulated Cycle (TAC) has been proposed. It allows the comparison of the actual operating time of the ATE in hours and the accumulated value of cyclic damage to the engine and its major components (within the TAC parameter) during the previous operation.

Keywords: *Afterburning Turbofan Engine, major components, cycle damage, Total Accumulated Cycle, technique, assigned resource.*

DESCRIPTION OF THE ISSUE

The operating time of some tactical aircraft engines of the Ukrainian Air Forces reaches the values assigned operating time. This fact intensifies the need for research on solving the issue of the further increase or individual extension in accordance with the technical condition of the major components (MCs) cycle life of the certain types of engines, provided that the safety of their use during the extended period is maintained. This raises a number of controversial issues related to the need for increasing the cycle life values of the ATE which are set up on fighters.

The design and technological peculiarities of ATE manifest themselves in the fact that the cycle life of certain rotor MCs is shorter than the overall cycle life of the engine where they are used. This leads to the need for replacing some MCs with new ones during the overhaul of the engine in order to ensure the further cycle life until the scheduled maintenance. It is known [1] that the MCs include the compressor and turbine rotor discs the cycle life of which is set within the loading cycles.

It is acceptable practice in aircraft engine building and tactical aircraft ATE operation in the United States and European countries [1, 2] to apply the TAC parameter as one of the key parameters which characterizes the depletion of the cycle life of both the engine and its MCs.

Accounting for the cyclic damage accumulation of certain MCs [3, p.1050] since being placed in service has been introduced in the recent engine modifications

which are used on such fighter aircrafts as Su-30, Su-34, Su-35 and others.

For the fourth-generation ATEs [3, p. 112; 4, p. 56] it is common practice to use electronic of the automatic control systems (EACS) which have 2 - 3 modes of settings (restrictions) of the defining parameters at maximum modes: rotor speed, turbine gas temperature, etc. where both the training or combat loading cycles are being implemented.

The purpose of the research is to substantiate the possibility of increasing the operating time resource of the MCs in accordance with the operating time of fighter aircraft engines which have significant operating time in the previous operating period in the absence of information on monitoring the accumulated damage throughout this period.

EXPERIMENTAL STUDY

Operational damage permissible values for the MCs of the ATE rotors in TAC are estimated by means of the calculation and experimental methods [1, 5] and are confirmed at equivalent-cyclic tests being part of an engine or on special acceleration benches. In accordance with [1] in general, the value of the engine TAC or its MCs is defined as follows:

$$TAC = \frac{N_1}{K_1} + \frac{N_2}{K_2} + \frac{N_3}{K_3} + \frac{N_{ST} - N_1}{K_4} \quad (1)$$

where N_1, N_2, N_3, N_{ST} stand for the number of total loading cycles of N_1 type and elementary cycles of N_2 and N_3 types, in which a certain amplitude of the rotor speed change is being realized [1, 5], as well as the overall number of engine starts N_{ST} in the previous

operation period; K_1, K_2, K_3, K_4 stand for the coefficients which determine the contribution rate to the engine TAC or MCs of its rotors in accordance with the total and elementary loading cycles, as well as engine starts without further implementation of the N_1 type total cycles in the process of their performance.

Formula 1 does not take into consideration the significant difference in the value of TAC which is accumulated in the rotor MCs depending on the EACS engine governor setting of the training or combat modes and cannot be applied to the engine MCs which have significant previous operation time as well as those engines the operating system of which lacks accounting for the cyclic damage of the rotor MCs since their placement in service, as it is provided for in [1; 2; 3, p. 7].

In the method which has been developed by the authors of this research the abovementioned shortcoming is eliminated by converting formula 1 to a form which has regard to this peculiarity of the EACS.

$$TAC_{MC} = \frac{N_{1C}}{K_{1C}} + \frac{N_{2C}}{K_{2C}} + \frac{N_{3C}}{K_{3C}} + \frac{N_{1T}}{K_{1T}} + \frac{N_{2T}}{K_{2T}} + \frac{N_{3T}}{K_{3T}} + \frac{N_{ST} - N_{1C} - N_{1T}}{K_4} \quad (2)$$

Where N_{1C} , N_{2C} and N_{3C} stand for the overall number of total and elementary cycles in the previous engine operation period while setting the EACS on the combat mode; N_{1T} , N_{2T} and N_{3T} stand for the overall number of total and elementary cycles in the previous engine operation period while setting the EACS on the training mode; K_{1C} , K_{2C} and K_{3C} stands for the coefficients which determine the contribution to the TAC MCs of the total and elementary cycles when the engine is running under the EACS setting on the combat mode; K_{1T} , K_{2T} and K_{3T} stands for the coefficients which determine the contribution to the TAC MCs of the total and elementary cycles when the engine is running under the EACS setting on the training mode; K_4 stand for the coefficient which determine the contribution to the TAC MCs of the engine start cycles after which it was not running at maximum mode.

Numerical values of the coefficients K_{1C} , K_{2C} , K_{3C} , K_{1T} , K_{2T} , K_{3T} and K_4 are determined by calculation and experimental methods [1, 5].

Thus, the general view of the TAC MCs value can be represented as follows:

$$TAC_{MC} = TAC_{MCCF} + TAC_{MCTF} + TAC_{MCGCM} + TAC_{MCGCI}, \quad (3)$$

where TAC_{MCCF} stands for the TAC value which has been accumulated by the engine rotor MCs in the process of performing flights when setting the EACS on

the combat mode; TAC_{MCTF} stands for the TAC value which has been accumulated by the engine rotor MCs in the process of performing flights when setting the EACS on the training mode; TAC_{MCGCM} stands for the TAC value which has been accumulated by the rotor MCs in the process of starting for the ground service maintenance with the engine running at maximum modes; TAC_{MCGCI} stands for the TAC value which has been accumulated by the rotor MCs while starting for the ground service maintenance with the engine running at idle power without the following transition to the maximum mode.

The research carried out by the State Research Institute of Aviation [6] outlines three groups of Typical Flight Cycles (TFC) of the ATE performance in the fighter flights which are implemented when setting the engine EACS on the "C" (combat) mode and are characterized by certain ratios (structure) of the elementary cycles being implemented in them:

$$\begin{aligned} TFC\ C1: & N_{1C} + 2 \cdot N_{2C} + 6 \cdot N_{3C}; \\ TFC\ C2: & N_{1C} + 0,5 \cdot N_{2C} + 6 \cdot N_{3C} \\ TFC\ C3: & N_{1C} + 2,5 \cdot N_{3C} \end{aligned} \quad (4)$$

There are also three groups of TFC which are implemented when setting the engine EACS on the "T" (training) mode and are characterized by the appropriate ratios (structure) of the elementary cycles being implemented in them:

$$\begin{aligned} TFC\ T1: & N_{1T} + N_{2T} + 7,5 \cdot N_{3T}; \\ TFC\ T2: & N_{1T} + 3,5 \cdot N_{3T}; \\ TFC\ T3: & N_{1T} + N_{3T}. \end{aligned} \quad (5)$$

According to the structure of the cyclic loading of the ATE and their MCs by the elementary cycles of the N_2 and N_3 types when performing flights, the abovementioned TFC have significant differences in the application of the engine EACS setting modes "C" and "T".

It has been found [6] that the realization probability of the TFC significantly depends on the modification of fighters (combat or training) on which the flights are performed. The reason for this lies in the differences in the sets of exercises performed mainly on aircrafts of certain modification, as well as the setting modes of the ATE which are used to perform them.

Proceeding from the mandatory implementation in each flight of the total cycle of the engine type N_1 and the familiar values of TAC in total and elementary cycles obtained earlier, the most probable structures of the Generalized Typical Flight Cycles (GTFC) of the ATE performance under the cyclic loading of one of the MCs have been formulated and described and appear as follows:

$$GTFC - C(C): N_{1C} + N_{2C} + 1,6 \cdot N_{3C};$$

$$\begin{aligned}
GTFC - C(T): & N_{1C} + N_{2C} + 4 \cdot N_{3C}; \\
GTFC - T(C): & N_{1T} + 0,25 \cdot N_{2T} + 3 \cdot N_{3T}; \\
GTFC - T(T): & N_{1T} + 0,33 \cdot N_{2T} + 5 \cdot N_{3T}.
\end{aligned} \quad (6)$$

where C - combat mode of the engine EACS; T - training mode of the engine EACS; (C) - combat modification of fighter; (T) - training modification of fighter.

The mathematical expectation prediction of the TAC realized in the GTFC have been defined for the mentioned structures.

The Operation Manual on accounting for the engine operating time at high and variable modes [7] has been developed and implemented proceeding from the use of engineering and logical analysis methods in order create the conditions for the practical calculation of the TAC MCs value.

Herein, the data from the engine log book since being placed in service in relation to the overall operating time and operating time at maximum modes is summarized. For the practical application of the data on the operating time of the engine since being placed in service which have been obtained in accordance with [6], formula 2 has been converted into formula 3:

$$\begin{aligned}
TAC_{MC} = & \sum_i^{N_{CF}} \overline{TAC}_{CFi} + \sum_j^{N_{TF}} \overline{TAC}_{TFj} + \\
& + \sum_k^5 \cdot \sum_l^{N_{GS1}} TAC_{GS1k,l} + \sum_m^{N_{GS2}} TAC_{GS2m} \quad (7)
\end{aligned}$$

where $\overline{TAC}_{CFi}$ stands for the mathematical expectation of the TAC MCs for the GTFC [1] of engine performance when setting the EACS on the combat mode being defined by statistical methods; $\overline{TAC}_{TFj}$ stands for the mathematical expectation of the TAC MCs for the GTFC of the engine performance when setting the EACS on the training mode being determined by statistical methods; $TAC_{GS1k,l}$ stands for the TAC MCs value under the k -th mode of ground engine test; TAC_{GS2m} stands for the TAC MCs value when the engine runs at idle power mode during the ground engine or aircraft system test; N_{CF} stands for the number of flights performed when setting the EACS on the combat mode; N_{TF} stands for the number of flights performed when setting the EACS on the training mode; N_{GS1} stands for the number of engine starts with the subsequent transition to the maximum mode during the ground test; N_{GS2} stands for the number of engine starts when the engine runs at idle power mode during the ground engine or aircraft system test; k stands for the type of ground engine test mode with remote control units during its service maintenance.

Thus, the balance of ΔTAC_{MC} which the engine rotor MCs have, can be defined (estimated) as follows:

$$\Delta TAC_{MC} = TAC_{MCP}^E - TAC_{MC}, \quad (8)$$

where TAC_{MCP}^E stands for the permissible operating value of the TAC_{MC} which is analogous in its physical essence to the permissible value of the MCs cyclic damage of the engine rotors [1, 5] and is defined as the ratio of the permissible value of the cyclic damage established as a result of the MCs test within the engine or test bench to the calculated value of its cyclic damage in one total cycle (type N_1 cycle) which is accepted as an actuation cycle.

The forecasted balance of the MCs cycle life of the ATE rotors in terms of the operating time (in time units) is defined as follows:

$$\tau = \frac{\Delta TAC_{MC}}{\overline{TAC}_{GTFC}} \cdot \tau_{GTFC}, \quad (9)$$

where $\overline{TAC}_{GTFC}$ stands for the mathematical expectation of the TAC_{MC} in the GTFC for a given period of engine operation which is determined by statistical methods; τ_{GTFC} stands for the forecasted duration of the GTFC for a given period of engine operation which is determined by statistical methods.

It has been found that there are certain consistent patterns for the number of implementations in the typical flights of elementary loading type N_2 and N_3 cycles which are given in [8...11] when setting the engine EACS on the combat mode as well as when using engines on the aircrafts of various modifications.

Figure 1 shows the general algorithm which implements the proposed operational technique for the rotor MCs of the military aircraft engines.

SUMMARY

1. Modern approaches, design concepts and implementation examples of monitoring the accumulated cycle damage of the MCs and functional parameters of the ATE systems, their operation in accordance with the technical condition have been specified proceeding from the analysis results of the existing system of the ATE MCs operation and accounting for their performance (thermomechanical loading).

2. It has been found that the options of increasing the MCs assigned operating time should be implemented by way of reducing the operating time at the maximum and reheat power modes and at low values of the major engine parameters at maximum and reheat power modes by way of reducing the turbine inlet temperature (switching on the "T" training mode).

3. The appropriate conditions for the introduction of an automated system for monitoring the accumulated cycle damage of the controlled MCs have been created on the basis of the developed operational technique for the MCs of the fighter ATE rotors.

4. It has been proved on the basis of the feasibility and experimental research that introduction of the

accounting for the depletion of the assigned operating time of the ATE MCs makes it possible to prolong their cycle life up to 30%.

The method and technique developed at the State

Research Institute of Aviation are protected by a utility model patent [12] and have been put into practice of the ATE overhaul and operation of the Ukrainian Air Force fighter aircrafts.

Figure 1. Algorithm for implementing the developed technique

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Надійшла до редколегії 10.11.2021

Схвалена до друку 12.12.2021

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**МЕТОД ЕКСПЛУАТАЦІЇ ОСНОВНИХ ДЕТАЛЕЙ РОТОРІВ
ТУРБОРЕАКТИВНОГО ДВИГУНА З ФОРСАЖНОЮ КАМЕРОЮ ЗГОРЯННЯ**

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Напрацювання деякими авіаційними двигунами літаків тактичної авіації Повітряних Сил досягає значень, які наближаються до призначеного ресурсу. Це обумовлює потребу у проведенні досліджень щодо розв'язання завдання подальшого збільшення або індивідуального продовження за технічним станом ресурсу основних деталей певних типів двигунів за умови забезпечення безпеки їх застосування у продовжений період. При цьому виникає низка проблемних питань, пов'язаних з потребою збільшення ресурсних показників парку турбореактивних двоконтурних двигунів з форсажною камерою згоряння (ТРДДФ), які встановлюються на літаках-винищувачах. У статті запропоновано метод експлуатації основних деталей роторів авіаційних двигунів літаків-винищувачів, який засновано на врахуванні реальних умов їх циклічного навантаження в кожному польоті або наземному випробуванні та апріорної інформації щодо експлуатації у попередній період. Доведено, що отримані при цьому технічні рішення не тільки узгоджуються з відомими методами обліку вичерпання ресурсу авіаційних ТРДДФ, але й надають додаткові можливості щодо врахування індивідуальних особливостей та умов їх циклічної навантаженості за весь час напрацювання. Крім того запропоновано спосіб оцінки вичерпання ресурсу за загальною кількістю накопичених повних циклів Total Accumulated Cycle (TAC), який дозволяє порівнювати фактичний наробіток авіаційних ТРДДФ в годинах і накопичене значення циклічної пошкодженості двигуна та його основних деталей (у параметрі TAC) під час попередньої експлуатації. На основі проведених розрахунково-аналітичних і експериментальних досліджень доведено, що впровадження обліку вичерпання циклічного ресурсу основних деталей ТРДДФ дозволяє продовжити їх ресурс на величину до 30 %.

Ключові слова: ТРДДФ, основні деталі, пошкодженість, ресурс, спосіб.