Computer Modeling & New Technologies, 1999, Volume 3, 136-139
Transport and Telecommunication Institute, Lomonosov Str.1, Riga, LV-1019, Latvia

DEVELOPMENT OF MATHEMATICAL MODEL OF THE ENGINE FOR DIAGNOSTICS OF THE FLIGHT GUIDANCE COMPUTING SYSTEM

MOH'D M. Y. ATTOUM, V. P. LABENDIK

Riga Aviation University, Lomonosov Street 1, LV-1019, Riga, Latvia,
E-mail: inform@rau.lv

The principles of creation of mathematical models (MM) of turbofan for onboard Flight Guidance Computing Systems (FGCS) and benches for their diagnostics are considered. The way of correction of equations of MM for the registration of displacement to the characteristic of the engine because of a wear of a flowing part while in service is offered.

1. Introduction

One of the most important tasks diagnosis of complex piloting-navigational equipment’s of modern and perspective problems in aircraft’s is the security of function ability monitoring of the Computerised Thrust Control System (CTCS), intended for defining the parameters regulating the thrust provided by the engines at automatic control during aircraft flights. As the thrust in flight is not measured immediately in CTCS, e.g. in aircraft IL-96, the conventional operational principle of working mode of the engines and accordingly thrust is used by providing rotation frequency high pressure rotor, however this connection non-linear, and it breaks upon the tear of a flowing part of the engine.

The developed software for diagnostic bench allows to change proceeding from human control to computer monitoring of flight control, e.g. used in offered mathematical model of the drive PS-90A, constant and linear connection between thrust and overfall of pressure behind the turbine and at the fan entrance ventilator.

2. Problem formulation

The mathematical model of the engine represents equations of values of a thrust, propellant consumption and measurement of parameters of the engine on base modes of flight.

For calculation of displacement of the high-altitude, fast-track and throttle because of a wear of a flowing part of the engine while in service, the linear mathematical model of the engine is used. It allows without series cyclical approximations immediately to decide a set of equations making mathematical model.

The elements of these equations are not absolute significance of parameters, and their relative deviations (from basic) as, for example, $\delta T = \Delta T/T \cong dT/T$. The factors before such elements of the equations are influence coefficients of the given parameter on an integrated parameter of the equation and shows a curvature performances on scale of points (they are determined on special expressions through significance's of parameters of a drive in base points).

Is indicated linear below, a mathematical model of turbofan drive with merging of streams, in which inlet cross section area, and also the full pressure loss coefficients in elements’ stator are accepted constant.

The equation of overfall of upstream pressures in the mixer from II outlines

$$\delta\pi_{KII}{}^{*} = \delta P_{II}{}^{*} - \delta P_{H} - 3{,}5 K_{V}\delta M \ . \qquad (1)$$

The equation of a modification of temperature behind the compressor II outlines

$$\delta T_{KII}{}^{*} = Q_{2}\left(Q_{n}\cdot\delta n_{1} + Q_{L}\delta\pi_{KII}{}^{*} - \delta\eta_{KII}{}^{*}\right) + \left(\delta T_{H} + K_{V}\delta M\right)\left(1 - 0{,}5Q_{2}Q_{n}\right). \qquad (2)$$

The equation of performance of the compressor II outlines:

$$\delta G_B = Q_m \delta n_1 + Q_{10}\delta\pi_{KII}{}^* + \delta p_H - 0{,}5(1+Q_m)\delta T_H + (3-0{,}5Q_m)K_V\delta M + 1 + Q_{10}\cdot\overline{Q}_{10}\cdot\delta\overline{G}_B\,, \quad (3)$$

$$\delta\eta_{KII}{}^* = Q_{11}\delta\pi_{KII}{}^* + \delta\overline{\eta}_{KII}{}^* - Q_{11}\cdot\overline{Q}_{10}\cdot\delta\overline{G}_B\,. \quad (4)$$

The equation of air consumption in outlines

$$dG_B = (1-K_{16})\delta G_{B1} + K_{16}\delta G_{B2} = \delta P_H + 3{,}5K_V\delta M +$$
$$(1-K_{16})\left[A_m\delta n_1 + A_{10}\delta\pi_{K1}{}^* - 0{,}5(1+A_m)\delta T_{KII}{}^* + \delta\pi_{KII}{}^* + \left(1+A_{10}\cdot\overline{A}_{10}\right)\delta\overline{G}_{B1}\right] + \quad (5)$$
$$K_{16}\left(0{,}5\delta T_{KII}{}^* + Q_6\delta\pi_{KII}{}^*\right)$$

The equation for temperature after fan second stage

$$\delta T_{K1}{}^* = A_2\left(A_n\delta n_1 + A_L\delta\pi_{K1}{}^* - \delta\eta_{K1}{}^*\right) + (1-0{,}5A_2A_4)\delta\pi_{K1}{}^*\,. \quad (6)$$

Modification of efficiency on performance after fan second stage

$$d\eta_{K1}{}^* = A_{11}\delta\pi_{K1}{}^* + \delta\overline{\eta}_{K1}{}^* - A_{11}.\,\delta\overline{G}_{B_1}\,. \quad (7)$$

The equation of overfall of pressure in 1 outline on withdrawal from the mixer

$$\delta p_1{}^* - \delta p_1 = \delta\pi_{K2}{}^* + \delta\pi_{K1}{}^* + \delta\pi_{K2}{}^* - \delta\pi_{T1}{}^* - \delta\pi_{T1}{}^*\,. \quad (8)$$

The equation of balance of costs through first exhaust apparatus of the turbine

$$\delta G_{B1} = \delta p_H + 3{,}5K_V\delta M + \delta\pi_{KII}{}^* + \delta\pi_{KI}{}^* + \delta\pi_{KII}{}^* - 0{,}5\delta T_\Gamma{}^*\,. \quad (9)$$

The equation of performances of the compressor of high pressure

$$\delta G_{B1} = \delta p_H + 3{,}5K_V\delta M + \delta\pi_{K2}{}^* + \delta\pi_{K1}{}^* + B_m dn_2 + B_{10}\delta\pi_{K2}{}^* -$$
$$-0{,}5(1+B_m)\delta T_{KI}{}^* + \left(1+B_{10}.\overline{B}_{10}\right)\delta\overline{G}_{B1}, \quad (10)$$

$$\delta\eta_{K2}{}^* = B_{11}\delta\pi_{K2}{}^* + \delta\overline{\eta}_{K_2}{}^* - B_{11}\cdot\overline{B}_{10}\,\delta\overline{G}_{B1}\,. \quad (11)$$

The equation of performances of turbines of high and low pressure

$$(1-0{,}5A_3A_4)\delta\pi_{T1}{}^* = 0{,}5A_4\delta\eta_{T1}{}^*, \quad (12)$$

$$(1-0{,}5B_3B_4)\delta\pi_{T2}{}^* = 0{,}5B_4\delta\eta_{T2}{}^* + K_6\left(\delta p_I{}^* - \delta p_1\right). \quad (13)$$

Temperature behind the first turbine from the equation of work of the turbine

$$\delta T_{T1}{}^* = \delta T_\Gamma{}^* - A_3A_4\delta\pi_{T1}{}^* - A_4\delta\eta_{T1}{}^*\,. \quad (14)$$

The equation of balance of potencies of work & of the compressor and turbine of high pressure

$$B_n\delta n_2 + B_L\delta\pi_{K2}{}^* - \delta\eta_{K2}{}^* + (1-0{,}5B_n)\delta T_{KI}{}^* = T_\Gamma{}^* + A_3\delta\pi_{TI}{}^* + \delta\eta_{T1}{}^*\,. \quad (15)$$

The equation of balance of a potency of the turbine of low pressure

$$\delta T_{T1}{}^* + B_3\delta\pi_{T2}{}^* + \delta\eta_{T2}{}^* = K_{20}\delta n_1 + K_{21}\delta\pi_{K1}{}^* + K_{22}\delta\pi_{K2}{}^* - K_{19}\delta\eta_{K2}{}^* +$$
$$+(K_{19}-1)\delta\eta_{K1}{}^* + K_{23}\delta T_{K2}{}^*\,. \quad (16)$$

Upstream pressure in the camera of merging

$$\delta p_1 = \delta p_2 = t\left\{X\delta p_1{}^* + y\delta p_2{}^* + Z\left(\delta T_T{}^* - \delta T_{KII}{}^*\right)\right\}. \quad (17)$$

The equation of temperature behind the turbine

$$\delta T_T{}^* = \delta T_{T1}{}^* - B_3B_4\delta\pi_{T2}{}^* - B_4\delta\eta_{T2}{}^*\,. \quad (18)$$

Average full downstream pressure from the camera merging

$$\delta p_C{}^* = K_{13}\delta p_1{}^* + (1-K_{13})\delta p_2{}^*\,. \quad (19)$$

The equation of draft in small deviations has a kind

$$\delta R = K_B\left[\delta p_H + 3{,}5K_V\delta M + K_C K'_C\,\delta\left(p_C{}^*/p_H{}^*\right)\right] + (1-K_R)(\delta G_B + 0{,}5\delta T_H + \delta M)\,. \quad (20)$$

The equation of fuel consumption

$$\delta G_T = \delta G_B + K5\delta T_\Gamma{}^* + (1-K_5)\left\{B_2\left(B_n\delta n_2 + B_L\delta\pi_{K2}{}^* - \delta\eta_{K2}{}^*\right) +\right.$$
$$\left. + \left(1-0{,}5B_2B_n\delta T_{K1}{}^*\right)\right\} \quad (21)$$

The modification of specific fuel consumption will be defined from expression

$$\delta C_{YD} = \delta G_T - \delta R\,. \quad (22)$$

In the equations (3), (4), (5), (7), (10), (11) in difference from [1] are entered Additional values $\delta\overline{\eta}_K^*$ и $\delta\overline{G}_B$, Describing condition of the compressor, namely, displacement of performance of the compressor (modification of significance's $\delta\eta_K^*$ и δG_B For want of, given, π_K^*) in at the process of wear and contamination of a tract of the compressor. Influence coefficient for want of $\delta\overline{G}_B$ Is equal

$$\overline{Q}_{10} = \left[\left(\pi_{K1}^* - \pi_{K0}^*\right)/\pi_{K0}^*\right] \cdot \left[G_{B0}/(G_{B1} - G_{B0})\right] = \left(\Delta\pi_{K1.0}^*/\pi_{K1.0}^*\right) \cdot \left(G_{B0}/\Delta G_{B1.0}\right) =$$
$$= \delta\pi_K^*/\delta G_B \approx \left(d\pi_K^*/dG_B\right) \cdot \left(G_{B0}/\pi_{K0}^*\right)$$

Displacements of a pressure head-line also are characterised, and together with it and mode's of a point (n=const.) equidistant curves but line of operating duties in at the process of wear and contamination of a tract (Figure 1) in at the process the drive remains serviceable, but the direct connection between draft and rotation frequencies of the shaft of the drive is infringed, therefore the mathematical model more and more ceases to be adequate to an actual drive. For its identification in operation it is necessary periodically to measure parameters of a condition of a drive and by recalculation and the corrective action in performances of compressors to make the coordination mathematical model with actual performances.

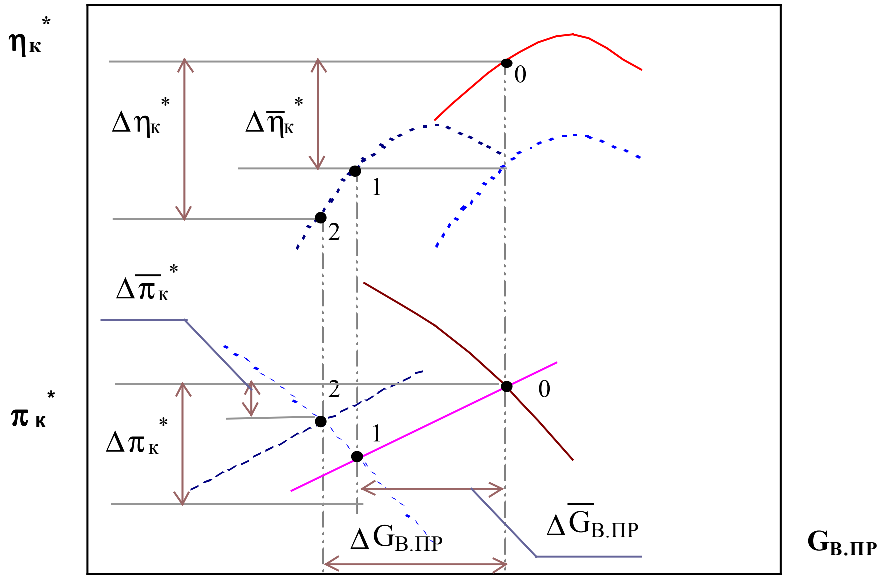

Figure 1. Otherwise management's of draft from the airborne computing system will happen to the increasing delay, i.e. the time of an output will be more and more increased by specific draft.

The method of the account of a displacement of performances is offered earlier by one of the authors in [2], but only for a turbojet drive, in the given work the offer is extended for a drive of more complicated scheme, as turbofan drive.

The second part of MM actuates calculation of transient regimes of engine run [3], that allows to use it for diagnostics FGCS in real-time mode.

3. Conclusions

For the test of the stand for half-full-scale simulation computerised thrust control system, is developed a universal linear mathematical model turbofan taking into account a shift of performances of compressors for want of wear through the flowing part.

The obtained mathematical model can be also used for diagnostics of the engine's thermo-gaseous-dynamic parameters, That is the deviations in measured values of the parameters on a comparison with initial, calculated value by the mathematical modes, it might localise defects in separate knots of a flowing part of a drive.

References

[1] Cherkez A. (1975) The engineering computing of gas turbine using the method of small deviations. Mechanical engineering's. Moscow. (in Russian).

[2] Kuznetsoff N. and Labendik V. (1993) Feature of forming diagnostic matrixes for monitoring a condition of a flowing part of turbofan. *Information VUZ « Air engineering. -Kazan: KAI, № 3.* (in Russian).

[3] Labendik V., Attoum M. (1997) Modeling of transient regimes turbofan. *The scientists of a slip of mechanical faculty*. RAU, № 3. Riga (in Russian).

Received on the 21st of June 1999