

M. S. KULYK, V. V. KOZLOV, L. G. VOLIANSKA

*National Aviation University, Kiev*

## AUTOMATION CONTROL SYSTEM OF TECHNICAL CONDITION OF GAS TURBINE ENGINE COMPRESSOR

*The article is devoted to one of the approaches to the construction of an automated system for solving the problems of diagnostics and monitoring of the flow duct of aircraft gas turbine engines and gas turbine plants. Timely detection of faults and subsequent monitoring of their development in operation are possible thanks to automated systems for assessing the technical condition of engines. This is particularly relevant in operating conditions as the knowledge of the technical condition of the engine is necessary for any engine maintenance system allows to choose the content and timing of maintenance, repair of the flow duct of gas turbine engines and gas turbine plants, as well as commissioning.*

*The engineering technique, which can be applied at the performance of maintenance and stages of tests and debugging of aircraft engines, is considered. The automated system implements a method of measuring the airflow through the compressor and a technique for assessing the technical condition of the compressor by the relative change in airflow.*

*To determine the airflow rate through the gas turbine engine, it is sufficient to measure only static pressure values in the flow part. The static pressure receivers are not located in the flow part and do not obscure it, and thus do not affect the compressor gas-dynamic stability margin. The inspection area is selected for measuring in the flow duct of the air intake. Static pressure in the maximum and minimum cross-sections of the chosen area is measured; the maximum cross-section area of the flow duct, the total temperature of the airflow is measured outside the air intake. To determine the airflow rate, the functional dependence of the airflow rate on the static pressure is used.*

*The algorithm for monitoring and diagnosing the operating condition of the engine is based on a comparison of the actual values of air flow rate with the airflow rate determined during the control tests or when using a mathematical model adapted for this gas turbine engine.*

*The positive effect of the using of the proposed automated control system of the technical condition is that the airflow rate measured under operating conditions will significantly increase the objectivity of the control of the operation and technical condition of the gas turbine engine.*

**Keywords:** *automated system; primary converters; metrological characteristics; air consumption; compressor; gas turbine engine; evaluation of technical condition; algorithm; metrological characteristics; functional scheme; approbation.*

### Introduction

The control system of any engine is designed to estimate the technical condition of the engine as a whole and as for its individual units and systems.

The estimation of the operating conditions of the gas turbine engine (GTE), gas turbine unit (GTU) refers to the control of their technical condition, both in accordance with the values of its main parameters with the requirements of the technical (operational) documentation, and according to the proposed criterion – the deviation of the air flow rate through the compressor. This allows us to determine not only the technical condition of the GTE, GTU, as a technical object, but also to es-

time the efficiency of maintenance, the current repair of the flow duct of GTE, GTU, debugging (engine sink, elimination of cracks, regulation of compressor mechanization, etc.).

Correct and timely estimation of the operational condition allows maintaining the reliability of controlled equipment at a given operational level.

Controlled objects represent a complex multilevel technical system. Analysis of the failures and troubles of individual systems and units [1, 2], allows to identify the most frequently damaged parts in the operation. One of these parts is the flow duct of the GTE, which interacts directly with the working fluid (air, gas). Timely detection of faults, their estimation, as well as the

subsequent control over their development in operation are possible due to automatic systems of estimation the technical condition of the GTE. The presence of efficient automatic systems based on modern methods (techniques) for estimation the technical state of the GTE are necessary in any system of their maintenance. Particularly relevant this factor is in operation conditions.

The basis of determination of airflow rate through the compressor is the following relationship [3]:

$$G = m \frac{P_B}{\sqrt{T_H^*}} F_B \left( \frac{k+1}{2} \right)^{\frac{1}{k-1}} \frac{\left( \frac{P_n}{P_B} \sigma_B \right)^{\frac{k+1}{k}} - A_B}{\left( \frac{P_n}{P_B} \sigma_B \right)^{\frac{2}{k}} - A_B} \times \sqrt{\frac{k+1}{k-1} \left[ 1 - \frac{\left( \frac{P_n}{P_B} \sigma_B \right)^{\frac{2}{k}} - A_B}{\left( \frac{P_n}{P_B} \sigma_B \right)^{\frac{k+1}{k}} - A_B} \right]} \quad (1)$$

where  $G$  – air flow rate, determined according the parameters of the air intake (Fig.1);

$m$  – coefficient taking into account the thermal physic properties of air;

$P_B$  – static pressure in the minimum section of the measuring area;

$T_H^*$  – total temperature of ambient air;

$F_B$  - area of the minimum section of the measuring area;

$k$  – adiabatic index;

$P_n$  – static pressure in the maximum section of the measuring area;

$\sigma_B$  – total pressure loss coefficient in the measuring part;

$A_B$  – coefficient of the flow duct cross section area change in the measuring part.

The value of  $m$  is determined as follows:

$$m = \sqrt{\frac{k}{R} \left( \frac{2}{k+1} \right)^{\frac{k+1}{k-1}}}$$

where  $R$  – gas constant, is a constant value and for air it is 287 J/kg K.

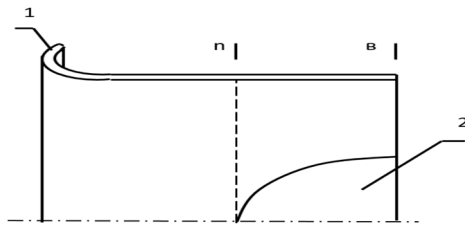


Fig. 1. The scheme of the flow part of the lemniscate air intake [4, 5]: 1 – air intake; 2 – engine air inlet nose cone; "n" – the maximum and "B" – minimum cross sections

In all engineering calculations adiabatic index  $k$  is accepted as a constant, the value of which for air is equal to 1.4.

The area of  $F_B$  is constant magnitude and is measured only one time.

The total pressure loss coefficient is a function of the Mach number  $M$  and in our conditions is taken to be a constant and equal to 1.0 [2, 3, 5].

The coefficient of the flow duct cross section area change in the inspection part

$$A_B \left( \frac{F_B}{F_n} \sigma_B \right)^2,$$

where  $F_n$  is the maximum area cross section of the inspection part, is a constant as  $F_B$  and is measured only for one time. So  $A_B$  is constant too.

Thus, to determine the air flow rate through the flow duct of the compressor, which is equipped with an axial air intake (Fig. 1), the next is needed:

1. pre-determine the constants  $k, F_B, F_n, \sigma_B, T, A_B$ ;
2. measure the temperature of the ambient air  $T_H^*$ ;
3. measure static pressure in the maximum area cross section of the measuring section  $P_n$ ;
4. measure static pressure in the minimum area cross section of the measuring section  $P_B$ ;
5. determine the air flow rate by dependence (1);
6. reduce the airflow rate to the Standard Atmosphere.

The basis of this method is the invention [3]. According to this method the air flow rate measurement is performed in the air intake of GTE on the section of the flow duct between the maximal and minimal cross sections.

When the constants are substituted into the above-mentioned dependence, it simplifies and takes the form of the function  $G = f(P_B, P_n, T_H^*)$ , where the external air temperature is measured by the regular receiver, and the static pressure values is measured by the using pilot-static tube, made in the form of openings with a diameter of 1 mm [3 - 5] in the sections "n" and "B", which do not obscure the flow duct of the air intake and do not affect the main parameters of the GTE and gas dynamic stability of the compressor.

Reducing of the air flow rate value to the Standard Atmosphere is carried out by the formula (2) [2 - 5]:

$$G_{red} = G_{cur} \frac{760}{P_H} \sqrt{\frac{T_H}{288}} \quad (2)$$

where  $G_{red}$  – the reduced value of air flow rate,  $G_{cur}$  – current value of air flow rate,  $P_H, T_H$  – pressure and temperature of air in front of the engine.

Thus, in order to determine the air flow rate passing through the GTE in the flow duct, it is sufficient to measure only the static pressure values, the receivers of which do not settle in the flow duct and do not obscure it and not affect the compressor gas-dynamic stability.

It is proposed to use a criterion changing of the air flow rate through the compressor to estimate the effectiveness of maintenance activities, in parallel with the estimation of the technical condition of the GTU. This criterion is compared with the permissible value for it and, a conclusion about the state of the GTU is made on the basis of this comparison. That is, this technique is based on a comparison of the actual values of air flow rate with the basic (initial), which are determined by the factory corresponding characteristic (acceptance test, throttle performance), or using a mathematical model adapted for this GTU.

### 1. Crux of problem

Minimizing the measurement of air flow through the compressor of the gas turbine engine, processing and filing the results without operator intervention.

#### 1. Construction of the basic flow characteristics

To construct, for example, the basic flow characteristics of the GTU D-336, the throttle performance of the gas turbine unit D-336 was used, the air flow of which is given in table. 1 in the form of functional relation  $G_{b.red} = f(n_{hp.red})$

Table 1  
The functional relation  $G_{b.red} = f(n_{hp.red})$

|                            |       |       |       |       |       |       |       |       |       |
|----------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $N_{hp, red},$<br>rev/ min | 12785 | 12920 | 13050 | 13170 | 13300 | 13425 | 13560 | 13700 | 13850 |
| $G_{b, red},$<br>kg/s      | 27,7  | 28,6  | 29,7  | 30,7  | 31,7  | 32,7  | 33,6  | 34,6  | 35,4  |

According to table 1 the approximation of the basic characteristics was carried out and it was got in the graphic (Fig. 2) and analytical form:

$$G_{b.red} = -258,0720310738 + 0,0361099896n_{hp.red} - 0,0000010768n_{hp.red}^2$$

This representation makes it possible to compare the actual value of the air flow rate with the base with the minimum error in the range of operating frequencies of the high pressure cascade rotor.

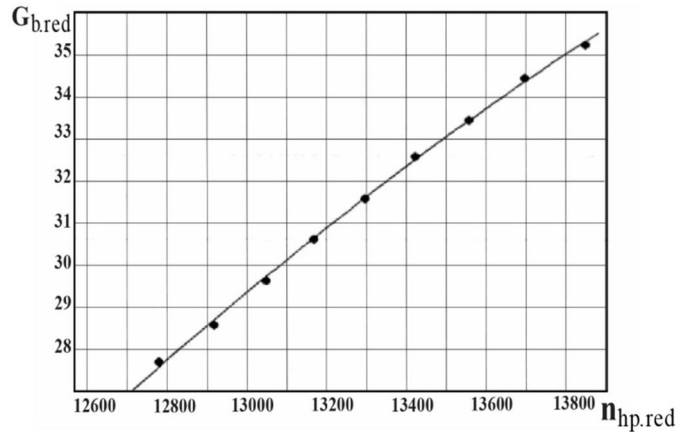


Fig. 2. Graphical representation of the basic characteristic

### 2. Algorithm for the measuring the air flow rate through the GTD

The algorithm for assessing the technical condition of the compressor is shown in Fig. 3.

In accordance with the algorithm, a software was done. It includes:

- program of diagnostics and installation of the technical part of the system;
- the software for calculating air flow rate and recording the results of measurements

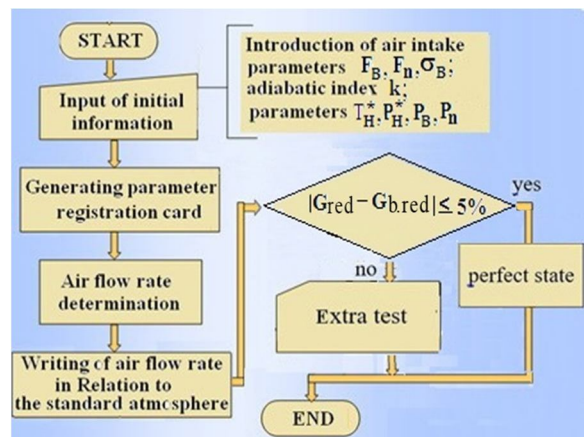


Fig.3.The algorithm for determining the air flow by an automated system

### 3. Automated system for measuring air flow through the gas turbine engine compressor

Automation system for measuring the air flow rate through the gas turbine engine compressor (Fig. 4) minimizes the operator's participation in the processing of the data. It implements the algorithm of air flow rate measurement method [4]. The method of determining the change of the air flow through the compressor and

consists of:

1. sets of primary signal converters, (receivers, sensors) installed on the gas turbine engine;
2. eight-channel communication with the object module;
3. electric cable;
4. data interface controller RS-422A/RS-485;
5. portable PC-based workstation;
6. software;
7. technical documentation.

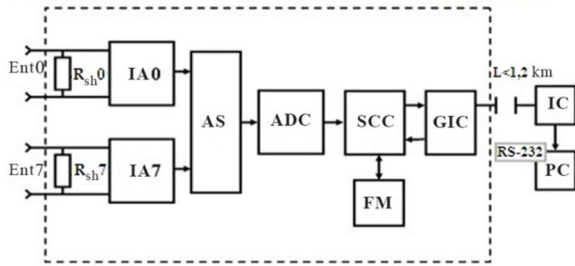


Fig. 4. Functional scheme of the automated system for measuring air flow rate through the compressor

In Fig. 4 the object communication module (MSO) is selected with the dashed line, where Ent0 ... Ent7 – analog inputs from sensors; IA0 ... IA7 – input amplifiers; AS – analog switching unit; ADC – analog-digital Converter; SCC – single-chip controller; FM – flash memory; GIC – galvanic isolated Converter; other modules of the system: KI – interface Converter; PC – workstation based on personal computer.

System specifications:

8. input signal from sensors – current 4...20 mA;
9. supply voltage – 220 V;
10. power consumption – no more than 30 W;
11. number of measurements per second – no more than 20;
12. error – 0,05%;
13. distinguishing ability – 16 bit;
14. isolation voltage – 2500 To;
15. ambient temperature – from -10 to +70 °C.

The primary converters are - temperature sensor and two pressure sensors. Each GTU has a standard temperature sensor, the signal from which can be used in the system. To measure the air temperature before GTU it is advisable to use a sensor type KVANT - DDTVN 5303/4B2A (-50...+ 650 °C), and to measure the static pressure in the air intake – sensors such as MDD-1-1000, MDD-Te-220-780, Merran-100-DIF Vn1350, Safir 2415, Honeywell 307536667-000 and

etc.

The pressure sensors of the type MDD-1-1000, MDD-Te-220-780, in particular used in the flight recorders, require a special converter to convert the analog signal into digital. Besides this their metrological characteristic requires testing of sensors once a year, so it's better to apply the sensors with more stable metrological characteristics and digital output like types Metran-100-DIF Vn1350, [6] Safir 2415, Honeywell 307536667-000.

Pressure sensors “Safir” have been made in Ukraine by Private JSC “Manometr-Kharkiv” since 1998 in accordance with the specification U24275859.002-99. They designed for continuous conversion of liquid and gas pressure into a unified electrical signal. The sensors “Safir” minimized the shortcomings of sensors such as “Sapfir-22” and its Russian analogs. The error associated with the influence of temperature and static pressure was reduced. Resistance to one-way overloads was increased. Structurally, the sensor is a device in which two units can be selected: the measuring unit and the electronic unit. Sensors for various parameters have a unified electronic unit. The sensor works follows: the pressure of the working fluid is transferred from the pressure receiver into the chamber (chambers) of the measuring unit where it is converted into the deformation of the sensing element associated with the strain gauge, which leads to a change in the electrical resistance of the strain gauges. The electronic unit converts this resistance change into a constant current signal output. The upper limits of measurements are shown in table 2.

Table 2

The upper limits of measures

| Measured physical quantity | Type of sensor | The upper limits of measures, kPa  |
|----------------------------|----------------|------------------------------------|
| Pressure difference        | 2415           | 0,63; 1,00; 1,60; 2,50; 4,00; 6,30 |

The maximum permissible displacement of “zero” (change in the output signal at zero pressure) as a percentage of the range of displacement of the output signal, which occurs due to changes in ambient temperature from the boundaries in the range of 23±2 °C to another temperature in the operating temperature range for every 10 °C, is determined by:

$$\Delta_{ot} = \pm \Delta'_{ot} [1 + 0,5(P'_{max}/P_{max})],$$

where  $\Delta'_{ot}$  – values taken from the table 2;

$P'_{max}$  – maximum upper limit of measurement for this sensor type;

$P_{max}$  – the actual value of the upper limit of measurements for this sensor type.

The relative change in the output signal range  $\Delta'_{dt}$ , which occurs due to changes in ambient temperature  $23 \pm 2$  °C to another temperature in the operating temperature range for every 10 °C, does not exceed  $\pm \Delta'_{dt}$  (given in table 3).

Table 3

Changing the output signal due to the influence of operational factors

| Sensors with limits of acceptable basic error | $\Delta'_{ot}, \%$ | $\Delta'_{dt}, \%$ |
|---|--------------------|--------------------|
| $\pm 0,20$                                    | 0,06               | 0,10               |
| $\pm 0,25$                                    | 0,08               | 0,12               |
| $\pm 0,50$                                    | 0,15               | 0,20               |

The change in the output signal of sensors with a range of 4...20 mA, which occurs due to a change in the voltage of the power source from 15 to 42 V does not exceed  $\pm 0,005\%$  of the range of the output signal for each 1V change in electrical voltage. The change in the output signal of the sensors for changes in load resistance does not exceed  $\pm 0,01\%$  of the range of the output signal for every 100Ω change in load resistance. The sensors remain in operating condition when the maximum permissible pressure is exceeded by 1,5 times. The service life of the sensors is 12 years. The mass of the sensor is 5,8 kg. Metrological characteristics of sensors «Safir» (Fig. 5), «Metran» (Fig. 6), "Honeywell" (Fig. 7) are given below.

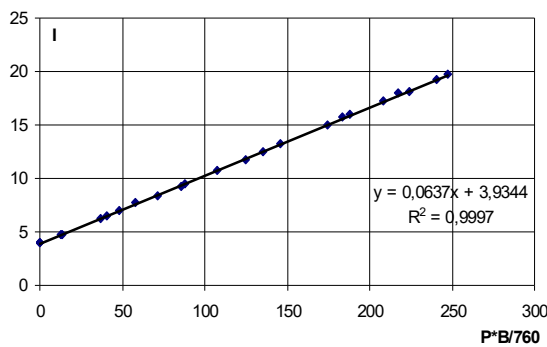


Fig. 5. Metrological characteristics of the pressure sensor "Safir" model 2415 №12179094

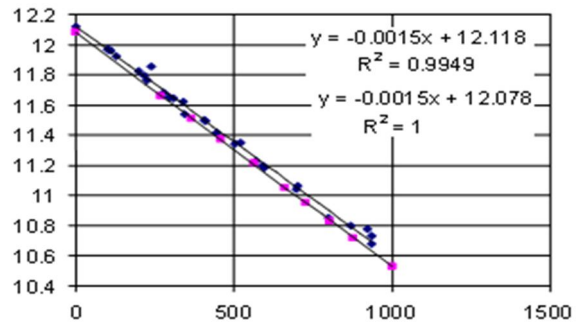


Fig. 6. Metrological characteristics of the pressure sensor Metran-100-DIF Vn 1350 №23748

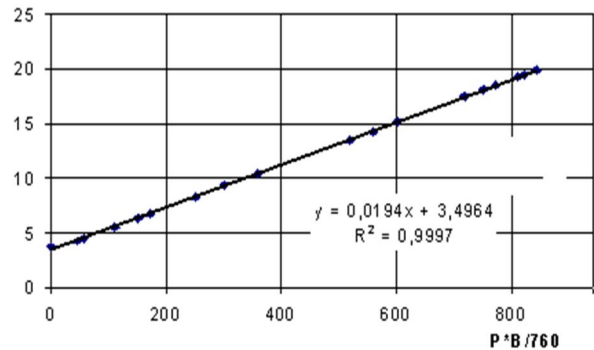


Fig.7. Metrological characteristics of the pressure sensor Honeywell 307536667-000

As the switch of the automated system, you can apply a switch-type  $\Phi 7071$  as analog-to-digital converter (ADC) –  $\Phi 7078$ , communication devices, and read-only memory (ROM) – K573P $\Phi$ , electronic computers – computer class Pentium 133.

The signals of the primary converters are fed to the ADC, which converts the analog signal to digital by the method of double integration. The digital signal is supplied to the ROM via galvanic ally-isolated elements and Protocol serial communication to a computer. The computer operates in real time and cyclically take the sensors readings. in the case of changes in the initial data the air flow is calculated according to the algorithm shown in Fig.3.

Parameters written by the system are automatically counted and presented as a flow characteristic by using the program SVZ\_1.EXE. Characteristics can be approximated with the standard program Excel, as a result of which we get the flow characteristics in both analytical and graphical forms, that allows to compare them. The initial (basic) characteristic is taken as the characteristic of the washed engine, that allows to evaluate divergence of parameter

$$\Delta G = \frac{G_{wash} - G_{filt}}{G_{wash}} 100\% .$$

Using the data of the test report, the air flow rates through the polluted engine and the same engine after



washing are reduced to standard atmosphere (table. 4).

Table 4

Data of the test report

| $n_{red\ pt}$ ,<br>rev/min | $G_{red\ filt}$ ,<br>kg/s | $n_{red\ pt}$ ,<br>rev/min | $G_{red\ wash}$ ,<br>kg/s |
|----------------------------|---------------------------|----------------------------|---------------------------|
| 5500                       | 15,785                    | 5550                       | 15,197                    |
| 6060                       | 15,949                    | 6050                       | 15,631                    |
| 6570                       | 17,311                    | 6520                       | 16,489                    |
| 7030                       | 18,457                    | 7020                       | 17,962                    |
| 6550                       | 17,211                    | 6510                       | 16,582                    |
| 6090                       | 15,909                    | 6040                       | 15,356                    |
| 5550                       | 14,484                    | 5550                       | 14,123                    |

According to this table, we approximate the obtained data and get a graphical and analytical representation of the flow characteristics before and after the engine washing. From the obtained data, it can be seen that the point of the first value of flow is significantly allocated among the General distribution, which is explained by the operation of the compressor bypass valves. Excluding these points, the approximation gives a linear distribution of the data (Fig.8).

With further comparison of the compressor flow characteristics of the polluted and washed engine, it is seen that an almost equidistant displacement of the engine flow characteristics in the entire range of its operating regimes. The maximum deviation of the characteristics is approximately 5%, which is inherent in the tolerance of the algorithm for evaluation performances of the compressor.

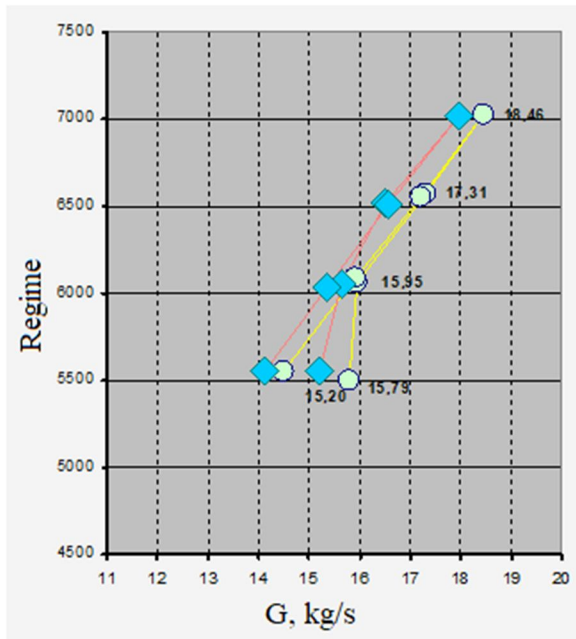


Fig. 8. Distribution of approximation data

## Conclusion

The automated control system of the technical condition of the gas turbine engine compressor described in the article has been tested at the engine test centre "Motor Sich", as well as at the underground gas storage in Dashava. The system has shown its efficiency, it does not cause in changes to the design of the engine and does not affect its gas-dynamic parameters, the margin of stability. It can be used on helicopters and ground gas turbine units with a lemniscate air intake.

The developed system allows for express control (operational control) in the current time.

## Literature

1. Козлов, В. В. Анализ и классификация дефектов, приводящих к отказам газотурбинных двигателей в эксплуатации [Текст] / В. В. Козлов // Методы и средства контроля технического состояния авиационных двигателей : Сб. науч. тр. – Киев : РИО КИИГА, 1989. – С. 128-135.

2. Лозицкий, Л. П. Оцінка технічного стану авіаційних ГТД: навч. посібник [Текст] / Л. П. Лозицкий, А. К. Янко, В. Ф. Лапшов. – М. : Транспорт, 1982. – 60 с.

3. Деклараційний патент на винахід №31969А України, МПК6 G01F 1/34. Спосіб виміру витрати повітря, що проходить через повітряно-реактивний двигун [Текст] / С. О. Дмитрієв, В. В. Козлов, М. С. Кулик та ін. ; заявник і патенто власник Національний авіаційний університет. - № 98116308; замовл. 30.11.98; опубл. 15.12.2000 р., Бюл №7-П. – 3с.

4. Горбунов, Г. М. Испытание авиационных воздушно-реактивных двигателей [Текст] / Г. М. Горбунов, Э. Л. Солохин. – М. : Машиностроение, 1967. – 256 с.

5. Солохин, Е. Л. Испытания воздушно-реактивных двигателей [Текст] / Е. Л. Солохин. – Москва : Машиностроение, 1975. - 366 с.

6. Датчики давления серии МЕТРАН [Текст]: Инструкция по настройке СПГК.5070.000.00 ИИ – Челябинск, 2003. – 68 с.

## References

1. Kozlov, V. V. Analiz i klassifikacija defektov, privodjashhij k otkazam gazoturbinnih dvigatelej v jekspluatácii [Analysis and classification of defects leading to failures of gas turbine engines in operation]. Metody i sredstva kontrolja tehničeskogo sostojanija aviacionnyh dvigatelej. Sb. nauch. tr., Kiev, RIO KIIGA Publ., 1989, pp.128-135.

2. Lozy'czky'j, L. P., Yanko, A. K., Lapshov, V. F. Ocinka tehničnogo stanu aviacijny'x GTD [Evaluation of technical state of aviation GTE]. Moscow Transport Publ., 1982. 60 p.

3. Dmitriev, S. O, Kozlov, V. V, Kulik, M. S Sposib vy'miru vy'traty povitrya, shho proxodyt' cherez povitryano-reaktyvnyj dvy'gun [Method of measuring air flow passing through an air jet engine: Declaration]. Patent for invention No. 31969A (Ukraine, MKK6 G01F 1/34) of 15.12. 2000.

4. Gorbunov, G. M., Solokhin, E. L. *Ispytanie aviacionnyh vozdushno-reaktivnyh dvigatelej* [Aircraft jet test], Moscow, Mashinostroenie Publ., 1967. 256 p.

5. Solokhin, E. L. *Ispytanija vozdushno-reaktivnyh dvigatelej* [Tests of air-jet engines]. Moscow, Mashinostroenie Publ., 1975. 366 p.

6. *Datchiki davlenija serii METRAN : Instrukcija po nastrojke SPGK.5070.000.00 IN* [Pressure sensors of the METRAN series : Instructions for configuring SPGK.5070.000.00 IN]. Chelyabinsk, 2003. 68 p

*Поступила в редакцию 17.05.2019, рассмотрена на редколлегии 7.08.2019*

## **АВТОМАТИЗИРОВАННАЯ СИСТЕМА КОНТРОЛЯ ТЕХНИЧЕСКОГО СОСТОЯНИЯ КОМПРЕССОРА ГАЗОТУРБИННОГО ДВИГАТЕЛЯ**

*Н. С. Кулик, В. В. Козлов, Л. Г. Волянская*

Статья посвящена одному из подходов к построению автоматизированной системы для решения задач диагностики и контроля проточной части авиационных газотурбинных двигателей и газотурбинных установок. Своевременное выявление неисправностей и последующий контроль за их развитием в эксплуатации возможны благодаря автоматизированным системам оценки технического состояния двигателей. Особенно актуальным это является в условиях эксплуатации, так как знание технического состояния двигателя необходимо в любой системе технического обслуживания двигателей, так как позволяет выбрать содержание и сроки технического обслуживания, текущего ремонта узлов проточной части газотурбинных двигателей и газотурбинных установок, а также наладочных работ.

Рассматривается инженерная методика, которая может быть применена при выполнении технического обслуживания, а также на этапах испытаний и доводки авиационных двигателей. Автоматизированная система реализует способ измерения расхода воздуха через компрессор и данную методику оценки технического состояния компрессора по относительному изменению расхода воздуха.

Для определения расхода воздуха, проходящего через ГТД достаточно провести измерения только статических значений давления в проточной части, приемники статических значений давления располагаются на внешней поверхности проточной части и не затегают ее, и тем самым не влияют на запас газодинамической устойчивости компрессора. Участок для измерения параметров выбирают в проточной части воздухозаборника. На данном участке измеряется статическое давление в максимальном и минимальном сечениях, максимальная площадь сечения проточной части; полная температура воздуха измеряется снаружи воздухозаборника штатной системой контроля силовой установки. Для определения расхода воздуха используют функциональную зависимость расхода воздуха от статических давлений.

Алгоритм контроля и диагностики технического состояния двигателя базируется на сравнении действительных значений расхода воздуха со значениями расхода определенными при проведении контрольно-сдаточных испытаний или при использовании адаптированной для данного газотурбинного двигателя математической модели.

Положительный эффект от использования предлагаемой автоматизированной системы контроля технического состояния заключается в том, что измеренный в эксплуатационных условиях расход воздуха существенно повысит объективность контроля работы и оценки технического состояния двигателя.

**Ключевые слова:** автоматизированная система; первичные преобразователи; метрологические характеристики; расход воздуха; компрессор; газотурбинный двигатель; оценка технического состояния; алгоритм; метрологические характеристики; функциональная схема; апробация.

## **АВТОМАТИЗОВАНА СИСТЕМА КОНТРОЛЮ ТЕХНІЧНОГО СТАНУ КОМПРЕСОРА ГАЗОТУРБІННИХ ДВИГУНІВ**

*Н. С. Кулик, В. В. Козлов, Л. Г. Волянська*

Стаття присвячена одному з підходів до побудови автоматизованої системи для вирішення завдань діагностики та контролю проточної частини авіаційних газотурбінних двигунів і газотурбінних установок. Своєчасне виявлення несправностей і подальший контроль за їх розвитком в експлуатації можливі завдяки автоматизованим системам оцінки технічного стану двигунів. Особливо актуальним це є в умовах експлуатації, тому що знання технічного стану двигуна, необхідно в будь-якій системі технічного обслуговування двигунів і дозволяє вибрати зміст та терміни технічного обслуговування, поточного ремонту проточної частини газотурбінних двигунів і газотурбінних установок, а також налагоджувальних робіт.

Розглядається інженерна методика, яка може бути застосована при виконанні технічного обслуговування, а також на етапах випробувань і доведення авіаційних двигунів. Автоматизована система реалізує спосіб вимірювання витрати повітря через компресор і методику оцінки технічного стану компресора по відносній зміні витрати повітря.

Для визначення витрати повітря, що проходить через ГТД, достатньо провести вимірювання тільки статичних значень тиску в проточній частині. Приймачі статичних значень тиску розташовуються зовні проточної частини і не затіюють її, і тим самим не впливають на запас газодинамічної стійкості компресора. Ділянку для виміру вибирають в проточній частині повітрязабірника. На обраній ділянці вимірюється статичний тиск в максимальному і мінімальному перерізах, максимальна площа перерізу проточної частини, але повна температура повітряного потоку вимірюється зовні повітрязабірника штатною системою контролю силової установки. Для визначення витрати повітря використовують функціональну залежність витрати повітря від статичного тиску.

Алгоритм контролю і діагностики технічного стану двигуна базується на порівнянні фактичних значень витрати повітря зі значеннями витрати, що визначені при проведенні контрольних-здавальних випробувань або при використанні адаптованої для даного газотурбінного двигуна математичної моделі.

Позитивний ефект від використання запропонованої автоматизованої системи контролю технічного стану полягає в тому, що вимірює в експлуатаційних умовах витрата повітря суттєво підвищить об'єктивність контролю роботи і технічного стану двигуна.

**Ключові слова:** автоматизована система; первинні перетворювачі; метрологічні характеристики; витрата повітря; компресор; газотурбінний двигун; оцінка технічного стану; алгоритм; метрологічні характеристики; функціональна схема; апробація.

**Кулик Микола Сергійович** – д-р техн. наук, проф., завідувач кафедри авіаційних двигунів, Національний авіаційний університет, Київ, Україна.

**Козлов Володимир Вікторович** – канд. техн. наук, доцент, професор кафедри авіаційних двигунів, Національний авіаційний університет, Київ, Україна.

**Волянська Лариса Георгіївна** – канд. техн. наук, доцент, професор кафедри авіаційних двигунів, Національний авіаційний університет, Київ, Україна.

**Kulyk Mykola** – doctor of technical sciences Sciences, prof., Head of the Department of Aviation Engines, National Aviation University, Kiev, Ukraine, e-mail: kulykms@nau.edu.ua, ORCID Author ID: 0000-0003-2149-4006, ResearcherID: 2963362, <https://scholar.google.com/citations?user=R-Tos1QAAAAJ&hl=ru>

**Kozlov Vladimir** – Candidate of Technical Science, docent, Professor of the Department of Aviation Engines, National Aviation University, Kiev, Ukraine, e-mail: vvk@nau.edu.ua, ORCID Author ID: 0000-0003-0728-7668, ResearcherID: 2973933, <https://scholar.google.com.ua/citations?hl=uk&user=yjnnNFwAAAAJ>

**Voliansky Larisa** – Candidate of Technical Science, docent, Professor of the Department of Aviation Engines, National Aviation University, Kiev, Ukraine, e-mail: lvolia@nau.edu.ua, ORCID Author ID: 0000-0001-9651-8776, ResearcherID: 2960907, <https://scholar.google.com/citations?user=fYtIIqsAAAAJ&hl=en>

**Рецензент:** д.т.н., професор кафедри збереження льотної придатності О.В. Гончаренко, Національний авіаційний університет, Київ, Україна.