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Express evaluation of technical condition of gas turbine engines

The article is devoted to the express evaluation of the technical condition of gas turbine engines (GTE) and gas turbine units (GTU) at a change of relative air flow through the compressor.

The evaluation of the technical condition of the GTE, GTU is checking of the compliance of the values of its main parameters of their technical condition to the requirements of technical (operational) documentation, and proposed criterion – the deviation of the air flow rate through the compressor. This allows to determine not only the type of technical condition of GTE, GTU, as a technical object, but also to estimate the effectiveness of maintenance, repair of the flow duct of GTE, GTU, washing of the engine, indentations removal, adjusting of the compressor mechanization, etc.).

Correct and timely evaluation of the technical condition allows you to keep the reliability of the controlled equipment at a given operational level.

Controlled objects are a complex multi-level technical system, analysis of the flow of failures and malfunctions of individual systems and components of its [1,2], allows to determine the part that is most often damaged in operation. This part is the flow part of the gas turbine engine, which directly interacts with the working fluid (air, gas). Timely detection of faults, their evaluation, as well as subsequent monitoring of their development in operation are possible thanks to automated systems for evaluation the technical condition of the GTE. The effective automated systems based on modern methods (techniques) of evaluation the technical condition of the gas turbine engine are required in any system of maintenance. This factor is particularly relevant in operating conditions according to the technical condition.

The elements of the flow part constantly interact with the working fluid. Therefore, to characterize the state of the flow part, it is possible with the gas-dynamic parameters of the working fluid, their deviation from the basic values. To do this, we will use a modified system for measuring air flow through the GTE compressor. According to these data performance curves (throttle and climate) are built for certain operating modes of the engine. Thermodynamic calculation of the engine is performed to obtain the base characteristics. The performance characteristics of this type of engine are built according to the operation data, which are corrected to standard atmospheric conditions. After that, they are compared with the base and the conclusion about the state of the GTE is made.

The general assessment of technical condition of GTE is offered to be carried out on relative change of the air flow rate through the compressor. Testing procedures were performed at GTE RU19-300 and GTU D-336-2.

The failure of modern gas-turbine engine and gas turbine unit does not happen very often in operation. According to the statistics of failures of gas turbine engines [1], most of the failures (90 %) are associated with the flow part. This is typical for GTU.

The characteristic damages of a gas turbine engine flowing part which can bring to early termination of engine operation are: indentations, bending, cracks, chips, breaks, wearing of tip surfaces; unshrouding of compressor blades; spalling of metal from the shroud of compressor blades; the freedom of the vanes; cracks, chips of a special layer on the compressor working rings; cracks of the compressor disk; cracks of combustion chamber; breaks of deflector of connecting pipe for the fuel feeding to the combustion chamber; coking of the fuel injectors; the burnout of flame tube; burn-out of elements of the combustion chamber; burnout of the turbine blades; burning the surface layer of turbine blades; erosion, bending, cracks, breakages of the turbine blades; cracks of turbine disks; unshrouding of turbine; metal residue on the turbine blades; loss of nozzle inserts; the low gas dynamic stability margin; surging; internal destruction of the support elements of the rotors; jamming of the rotor; the excess engine vibration. This list of damages and malfunctions of elements of a gas turbine engine flowing part is characteristic for all their types.

Such defects as contamination, corrosion, erosion of the blades, the increase of the radial gaps between the tip of rotor blades and the working rings lead to lower efficiency of compressor, turbine components and on the whole of gas turbine engine; reduction of the engine power, compressor capacity, compressor gas dynamic stability margin and excess of fuel consumption.

The main malfunctions of GTU, which are considered in this work are:

- contamination of the flow part;
- erosion of compressor and turbine blades;
- corrosion of compressor and turbine blades;
- increase radial clearance between rotor and stator;
- coking of the injectors of the combustion chamber;
- deformation damage (curvature, indentations).

Among these faults are the most common contamination of the flowing part of the engine, which are periodically removed by washing a flowing part of the engine . This does not always achieve the desired effect. Therefore, it would be more appropriate to carry out this work on the actual condition of the engine. The same applies to the decision to carry out adjustments and repair of the engine.

Analyzing the various ways of estimation the technical condition of the GTE [3,4], it is possible to determine that it is necessary to provide measurements of the parameters of the operating process only for the similar modes, besides, the number of these parameters should be sufficient, and the measuring process of these parameters should not significantly affect the gas-dynamic stability of the compressor and its other characteristics.

If the dependence for evaluation of the technical condition of the compressor contains the values of total temperature and total pressure, then detector of total temperature and total pressure must be embedded in the elements of the flow part, for example, in the vanes. When this is not possible (based on the design features of the engine), the mathematical dependence should be rebuilt in such a way, where the total parameters will be replaced by static parameters, static pressure and static temperature.

The simplest parametric method for evaluation of the technical condition of the GTE is based on the air flow rate through the GTE. The air flow rate through the GTE is a functional parameter, and it can be measured in the real-time operation mode for the modern element base.

A method of measuring air flow rate through the GTE

The basis of this method is the invention [5]. 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 (Fig.1).

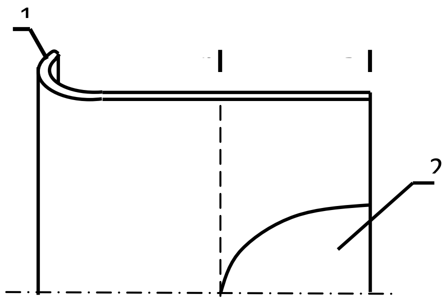

Fig. 1. Scheme of flow duct of the air intake: 1- air intake; 2- inlet fairing; "n" and "в"- maximal and minimal sections

According to this method the static pressure in the maximal and minimal cross sections of the measured part, their areas, the total temperature of the air in front of the air intake are measured, and the air flow rate is calculated by the following mathematical dependence:

$$G = m\,\frac{P_{\text{в}}}{\sqrt{T^{*}_{\text{н}}}}\,F_B\left(\frac{k+1}{2}\right)^{\frac{1}{k-1}}\frac{\left(\frac{P_n}{P_{\text{в}}}\sigma_{\text{в}}\right)^{\frac{k+1}{k}}-A_{\text{в}}}{\left(\frac{P_n}{P_{\text{в}}}\sigma_{\text{в}}\right)^{\frac{2}{k}}-A_{\text{в}}}\sqrt{\frac{k+1}{k-1}\left[1-\frac{\left(\frac{P_n}{P_{\text{в}}}\sigma_{\text{в}}\right)^{\frac{2}{k}}-A_{\text{в}}}{\left(\frac{P_n}{P_{\text{в}}}\sigma_{\text{в}}\right)^{\frac{k+1}{k}}-A_{\text{в}}}\right]}. \quad (1)$$

where

G – air flow rate;

m – coefficient taking into account the thermophysical properties of air;

P_B – static pressure in the minimal cross section of the measuring section;

T_H^* – total temperature of ambient air;

F_B – area of minimal cross section of the measuring section;

k – adiabatic exponent;

P_n – static pressure in the maximal cross section of the measuring section;

σ_B – the coefficient of the total pressure losses through the measuring section;

A_B – the coefficient of the flow duct cross-sectional area change.

Value of coefficient taking into account the thermophysical properties of air m is determined as:

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

where R= 287 [J / K] - the gas constant of air.

The adiabatic exponent k is taken as a constant in all engineering calculations, the value of which for air is 1.4.

The area F_B is constant value and is measured only once.

The coefficient of the total pressure losses is a function of the Mach number M and in our conditions is assumed to be constant and equal to 1.0 [6].

The coefficient of the flow duct cross-sectional area change

$$A_в = \left(\frac{F_в}{F_п}\sigma_в\right)^2,$$

where F_n – is the area of the maximal cross-section of the measured area, which like F_B is a constant value and is measured only one time. Thus the coefficient of the flow duct cross-sectional area change is constant $A_в$=*const*.

So, to determine the air flow rate through the compressor, which is equipped with an axial air intake (Fig.1), it is enough:

- define constants k, F_B, F_n, σ_B, m, A_B;
- to measure the ambient air temperature, T_H^* ;
- measure static pressure in the maximum cross-section of the measuring section, P_n;
- measure static pressure in the minimum cross-section of the measuring section, P_B;
- to determine the air flow rate according to (1);
- correct the air flow according to the automatic control system.

Taking into account that values of some parameters are constant the dependence given above is simplified and takes the form of a function $G = f(P_B, P_n, T_H^*)$, where the temperature of ambient air is measured by a standard sensor, and static pressure is measured by static pressure detector made in the form of holes with a diameter of 1 mm [5] in the cross sections “n” and “ в”, which do not obscure the flow part of the air intake and thus do not affect the main parameters of the gas turbine engine and the gas-dynamic stability of the compressor.

Correcting of the current value of the air flow rate is performed by the formula (2) [2,6]:

$$G_{ПР} = G_{ВИМІР}\frac{760}{P_H}\sqrt{\frac{T_H}{288}}, \quad (2)$$

where $G_{ПР}$ – corrected value of the air flow rate, $G_{ВИМІР}$ – the current value of the air flow rate, P_H ,T_H – pressure and temperature of ambient air before the engine.

Thus, to determine the air flow rate through the gas turbine engine, it is enough to measure only static pressure values, the detectors of which are not located in the flow part and do not obscure it, thereby not affecting the gas dynamic stability of the compressor.

Measuring system of air flow rate through GTE, GTU and its approbation

A prototype system for measuring air flow rate through GTE, GTU consists of the total temperature sensor (П -5), two static pressure sensors of the type МДД -Те-220-780 or МДД -1-1000, two detectors of static pressure, the pipeline, two electronic multimeters M838. Static pressure detectors 6 are connected to the corresponding sensors 5, and those by means of an electric cable are connected with an electronic device 7 (Fig.2). The system was tested on full-scale GTU Д-336-2 № 7083362720024. The presence of pressure sensors in the system required their metrological evaluation on a special test bench, as a result of which their metrological characteristics were obtained (Fig.3.4).

<u>Note:</u> the static pressure detector in section b was installed instead of the anti-icing sensor plug in the front housing of the compressor 4.

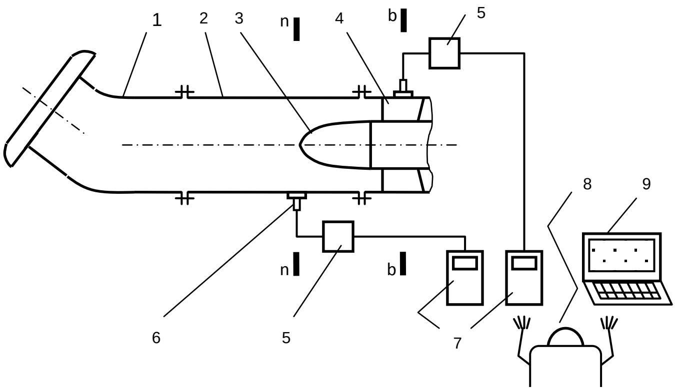

Fig.2. The scheme of the air flow rate measuring system with a change in static pressure in sections n and b

1– air intake; 2– spacer; 3– inlet fairing; 4– inlet guide vane; 5– pressure sensors; 6– static pressure detectors; 7– digital tester; 8–operator; 9– computer.

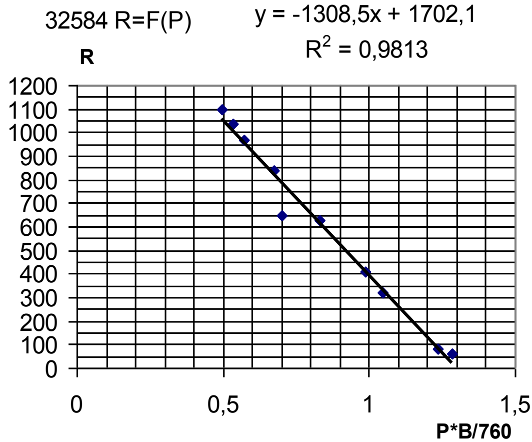

Fig.3. Metrological characteristics of the sensor МДД-1-1000 №32584

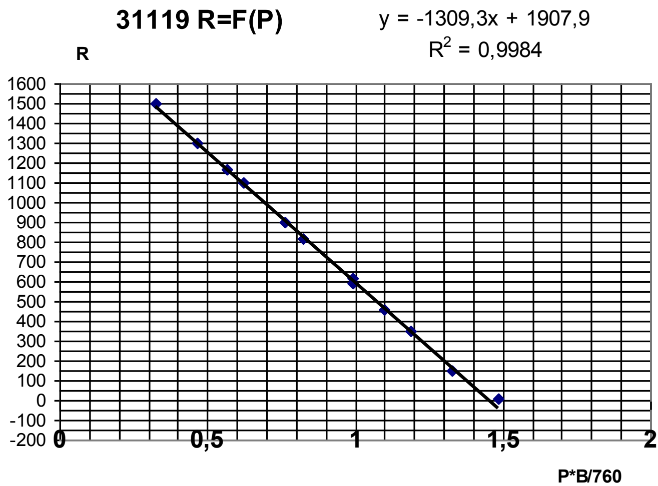

Fig. 4. Metrological characteristics of the sensor МДД - 1 -1000 №31119

Note that the installation of the air flow measurement system through the compressor does not change the design of the GTE, does not affect its gas-dynamic parameters and is operable.

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