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КАФЕДРА АВІАЦІЙНИХ ДВИГУНІВ

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КВАЛІФІКАЦІЙНА РОБОТА
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«МАГІСТР»
ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«ТЕХНІЧНЕ ОБСЛУГОВУВАННЯ ТА РЕМОНТ ПОВІТРЯНИХ СУДЕН І АВІАДВИГУНІВ»

Тема: «метод діагностування поступової деградації проточної частини турбовального двигуна»

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Київ 2021

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

EDUCATIONAL AND RESERCH AEROSPACE INSTITUTE
AEROENGINE DEPARTMENT

PERMISSION FOR DEFENCE
Head of the Department
Ph.D., Professor.
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«__»_________2021 p.

MASTER DEGREE THESIS
(EXPLANOTARY NOTE)

GRADUATE EDUCATIONAL DEGREE
«MASTER»
FOR EDUCATIONAL-PROFESSIONAL PROGRAM
«MAINTENANCE AND REPAIR OF AIRCRAFT AND AVIATION ENGINES»

Theme: « method of diagnostic gradual degradation of a turboshaft engine flow path.»

Performed by: __________ **R. V. Yaremchuk**

Supervisor: Ph.D. in Technology, Associate Professor, Senior researcher __________ **O. S. Yakushenko**

Consultants from separate sections of the explanatory note:

Labour precaution advisor: Ph.D., Assoc. Professor __________ **V. V. Kovalenko**

Environmental protection advisor: Ed.D., Professor __________ **T. V. Sayenko**

Standards Inspector __________

Kyiv 2021

NATIONAL AVIATION UNIVERSITY

Institute: *The Aerospace Faculty*
Faculty: *The Aircraft Faculty*
Department: *Aeroengines Department*
Educational and Qualifications degree: *Master*
The specialty: 272 Maintenance and Repair of Aircraft and Aeroengines

APPROVED BY
Head of the Department
________ Y. M. Tereshchenko
"____"_____________2021

Graduate Student's Degree Work Assignment

YAREMCHUK ROSTYSLAV VOLODYMYROVYCH

1. The Work (Thesis) topic: *Method of diagnostic gradual degradation of a turboshaft engine flow path.*

Approved by the Rector's order of 04 "October", 2021 № 2137/ст.

2. The Graduation Project to be performed: *October 25-2021—December 22-2021.*

3. Initial data for the project: *turboshaft engine should be designed for standard atmospheric conditions: T amb=288 K, P amb = 101.3 kPa, Ne =1660 kVt.*

4. The contents of the explanatory note (the list of problems to be considered):.

5. The list of mandatory graphic materials:

6. Schedule of Graduation Work Performing

Stages of Graduation Work Completion	Stages Completion Dates	Remarks
Literature review of materials concerning the project	28.09.21-15.10. 21	
Modeling standard engine model	15.10.21-07.11.21	
Modeling damage accumulation model	08.11.21-20.11.19	
Create method for diagnosing the flow path of a gas turbine engine using thermo and gas dynamic calculation	21.11.21-30.11.21	
Labor precaution	01.12.21-12.12.21	
Environmental protection	01.12.21-12.12.21	
Arrangement of graphical part of diploma work	12.12.21-18.12.21	
Preparation of explanatory note	14.12.21-20.12.21	

7. Advisers on individual sections of the work (Thesis):

Section	Adviser	Date, Signature	
		Assignment Delivered	Assignment Accepted
Labor precaution	Ph.D., Associate Professor V. V. Kovalenko		
Environmental protection	Ed.D., Professor T.V. Sayenko		

8. Assignment issue date ______________________________

Graduate Project Supervisor ______________________ O. S. Yakushenko

(supervisor signature)

Assignment is accepted for performing:

Graduate student ______________________ R. V. Yaremchuk

(graduate student’s signature)

ABSTRACT

The explanatory note to master's degree work: «Method of diagnostic gradual degradation of a turboshaft engine flow path»:

98 pages, 41 figures, 3 tables, 65 literature sources.

Object of study – prototype of turboshaft engine TV3-117

Subject of study – development of diagnostic methods

The purpose of degree work – the development of a method for diagnosing the flow path of the turboshaft engine based on the analysis of thermodynamic and gas-dynamic parameters of the working process.

The scientific novelty of the thesis is method of diagnosing gradual changes in the technical condition of the flow path, using the methods of mathematical statistics.

Research method - Elements of the theory of aviation gas turbine engines were used in scientific research to solve the set tasks; modeling of the process of degradation of the flow path of the engine and its detection by numerical experiment and processing of its results, detection of dependence.

CONTENT

INTRODUCTION

Increasing requirements for the safety and regularity of aircraft flights necessitated an ever-wider introduction into the practice of operating enterprises of methods and means of technical diagnostics, including aviation engines. The practical application of diagnostic methods determined the need for enterprises in engineering personnel with appropriate training, which was reflected in the state educational standard for training specialists. in the direction 652700 "Testing and operation of aviation and rocket and space technology". In this document, the qualification requirements state that the engineer must know the methods and means of assessing and managing the technical condition of aviation technology. To ensure these requirements in the implementation of the educational process, the discipline "Reliability and technical diagnostics" has been introduced into the list of compulsory disciplines.

This discipline is basic for the study of such disciplines as "Technical operation of aircraft and aircraft engines", "Technological processes for the maintenance of aircraft and aircraft engines."

At present, the educational literature devoted to the issues of diagnosing aviation equipment is clearly insufficient. And educational literature, from a unified position and at the modern level, covering the issues of control and diagnostics of aviation gas turbine engines in terms of thermogasdynamic and vibroacoustic parameters, is simply not there.

The proposed textbook is an integral part of the educational and methodological complex of the discipline "Reliability and Technical Diagnostics". In the course of mastering this discipline, students received theoretical knowledge and practical skills that allow them to assess the technical condition of aviation equipment, including monitoring and diagnosing aviation gas turbine engines by thermogasdynamic and vibroacoustic parameters. This knowledge and skills are essential for aircraft operating professionals.

Technical diagnostics is a science that arose in connection with the increasing role of complex and expensive technical systems in the national economy and the imposition of increased safety, reliability and durability requirements on them. In this regard, special requirements are imposed on aircraft, the failures of which lead to serious consequences.

Prevention of aircraft failures is largely determined by the effectiveness of methods and means of their diagnostics. The requirement for the need to have a system for monitoring the technical condition (TC) of an aircraft is contained in such a fundamental document as Aviation Regulations AP-25 "Airworthiness Standards for Transport Category Aircraft". According to these requirements, for aircraft systems, the failure of which can serve as a direct cause of a hazardous situation in flight, control and diagnostics of their vehicles should be provided. Such systems include engines of aircraft power plants.

Aviation GTE, which are complex structural and functional systems, are characterized by the appearance in operation of a variety of failures and malfunctions of various physical nature. A wide range of aircraft GTE failures and malfunctions cannot be detected by one diagnostic method. Practice confirms that in order to identify all possible malfunctions of a gas turbine engine, a developed system of technical diagnostics is required, based on a combination of various methods and tools. Among the variety of methods for diagnosing gas turbine engines, methods for diagnosing gas turbine engines and their units by thermogasdynamic and vibroacoustic parameters have become widespread.

This tutorial discusses the issues of diagnosing gas turbine engines and their units by thermogasdynamic and vibroacoustic parameters. The following issues are reflected in it.

General information about the methods of technical diagnostics is given: basic concepts, terms and definitions are given; the place of technical diagnostics in the system of technical operation was determined; the classification of methods of technical diagnostics is considered; the basics of creating

"Mathematical models" used in technical diagnostics, and, in particular, in methods of diagnostics of gas turbine engines by thermogasdynamic and vibroacoustic parameters.

When setting out the issues of diagnostics of gas turbine engines by thermogasdynamic parameters, the influence of malfunctions of GTE units and systems on thermogasdynamic parameters and characteristics of engine units is analyzed. The principles of control and diagnostics of the state of a gas turbine engine by thermogasdynamic parameters are considered. The description of the gas turbine engine by mathematical models and the principles of diagnostics using mathematical models are given. The issues of the influence of the measurement accuracy of thermogasdynamic parameters on the results of diagnostics are considered, examples of the application of methods for diagnosing gas turbine engines by thermogasdynamic parameters are given.

When describing the issues of diagnostics of gas turbine engines by vibroacoustic parameters, information is provided on the characteristics and parameters used to describe vibroacoustic processes, on methods and means of measuring and analyzing vibroacoustic processes. A description of the sources and reasons for the excitation of vibroacoustic processes by various units of the gas turbine engine is given. Mathematical models used to describe vibroacoustic processes and the principles of identifying the characteristics of vibroacoustic processes are considered.

Further, the issues of GTE vibration control (principles of vibration control, information about the onboard GTE vibration control equipment) and the issues of diagnostics of GTE and their units (reasons for changes in rotary vibration, bearing units, gear drives, blade units, etc.) by vibroacoustic parameters are considered.

The manual is intended for students studying in the specialty 160901 "Technical operation of aircraft and engines" and studying the discipline "Reliability and technical diagnostics",

"Technical operation of aircraft and aircraft engines". It can also be used by students enrolled in other aeronautical specialties.

PART 1

GENERAL INFORMATION ABOUT THE METHODS OF TECHNICAL DIAGNOSTICS

1.1. Basic concepts, terms and definitions

Technical diagnostics (TD) is a field of knowledge covering the theory, methods and means of determining the technical state of an object, including an aviation GTE. Like any science, it operates with the corresponding concepts, terms and definitions that are used both in the literature on general issues of technical diagnostics and diagnostics of aviation equipment, including diagnostics of aircraft engines.

In technical diagnostics, concepts, terms and definitions are used, the meanings of which are established by standards GOSTs. In addition, there are a number of terms and concepts that are not included in GOSTs, but are used in scientific, technical and educational literature. Below are the most commonly used terms and definitions.

In the definition of TD, the key concept is the concept of "technical condition". The technical condition of an object is understood as a set of object properties subject to change during production or operation, characterized at a certain point in time by the parameters (state parameters) established by the technical documentation for this object.

The object of technical diagnostics is a product and (or) its component parts subject to (exposed) diagnostics. That is, it is a material object for which the technical condition is determined and, as a result, a technical diagnosis is established. To make a diagnosis, it is necessary to assess the compliance of the condition parameters with the requirements of regulatory and technical documentation.

A state parameter is a quantity that quantitatively characterizes one of the main properties of an object or a process taking place in an object. Mass, coefficient of friction, geometric dimensions, clearances, electrical resistance, etc. can be taken as state parameters. These parameters are also called primary. An experimental assessment of the numerical values of these parameters and their comparison with the values specified by the regulatory and technical documentation, and allows you to assess the technical condition of the object, that is, to establish its diagnosis.

In practice, it is often impossible to directly measure the condition parameters. Therefore, in technical diagnostics, the concept of diagnostic parameters (DP) is introduced, which are understood as the parameters of the object used in the diagnostic process. These parameters in

technical literature is sometimes called secondary. As a DP, both technical state parameters and parameters that characterize various processes occurring in the diagnostic object and are only indirectly related to the state parameters can be used.

Thus, the assessment of the technical condition is carried out on the basis of information on the values of the diagnostic parameters. Therefore, the relationship between diagnostic parameters and condition parameters must be known. This connection is established using the so-called mathematical (diagnostic) models.

1.2. General information about GTE diagnostic methods and their classification

To determine the technical state of a gas turbine engine as a complex hydro mechanical system, a wide range of methods and means of technical diagnostics are required, which use diagnostic parameters of various physical nature.

Depending on the physical nature of the diagnostic parameters and the method of their measurement, there are physical and parametric diagnostic methods.

Physical methods are based on the use of various physical phenomena accompanying the operable or inoperative state of an object.

The physical methods primarily include non-destructive testing (NDT) methods, namely the following methods: optical-visual, capillary, magnetic control, eddy currents, ultrasonic, radiation. These methods are most widely used in the operation of aviation technology.

The physical methods for diagnosing objects include such a specific method as the method for diagnosing friction units based on the accumulation of wear products in the oil. It is known from operating experience that some of the failures of aviation equipment are associated with a malfunction of friction units due to unacceptable wear. The process of destruction of rubbing parts begins, as a rule, with the destruction of the surface layer of the material under the action of high contact stresses, which manifests itself in the form of separation of material particles. These particles are carried away by the oil. By their presence and concentration, one can judge the occurrence and development of a malfunction.

Thermal methods based on the analysis of thermal (infrared) radiation of elements, parts or the whole object are also referred to as physical methods. An efficient (serviceable) product has a certain pattern of thermal radiation. A change in this picture indicates a change in the operating mode or technical condition of the product.

The physical methods also include vibroacoustic methods of control and diagnostics, which are based on the analysis of the characteristics of noise and vibration of products. It is known that the characteristics of noise and vibration depend on the technical condition of the machine. During operation, there is a change in the technical state of the units and parts of the diagnostic object, as well as the working processes taking place in it. As a result, vibration and noise characteristics will also change.

Parametric methods are based on the measurement of diagnostic parameters that are directly related to the functional purpose of the object, and in some cases directly characterize its technical condition (for example: gas temperature behind the turbine, oil pressure, efficiency, etc.). Parametric methods are widely used in the diagnosis of aviation technology, including aviation gas turbine engines.

A number of authors understand parametric diagnostics as diagnostics using any measured parameters. With this interpretation, vibroacoustic and thermal methods fall into the category of parametric methods, which does not correspond to the classification proposed in.

The specified wide range of technical diagnostics methods is used to determine the technical condition at all stages of the life cycle of aviation gas turbine engines. However, for a number of reasons, a very limited range of diagnostic methods is used in operation. According to a number of authors, the following diagnostic methods are the most promising for assessing the technical condition of aviation gas turbine engines under operating conditions:

- based on the results of the analysis of thermogasdynamic parameters;
- by vibroacoustic parameters;
- by thermal parameters;

- tribodiagnostics;
- optical-visual diagnostics.

In accordance with generally accepted concepts, thermogasdynamic parameters include: pressure, temperature, ratio of pressures and temperatures, flow rate, fuel and oil consumption, flow area of the flow path, thrust, and rotational speed of the rotors. Therefore, diagnostic methods based on thermogasdynamic parameters should be classified as parametric methods.

To minimize the errors in assessing the state of the gas turbine engine based on the results of the measured thermogasdynamic parameters, the parameter values lead to standard atmospheric conditions, and the parameters are measured at the same altitudes and engine operating modes.

Monitoring and diagnostics by thermogasdynamic parameters is carried out by comparing the parameter values with the maximum permissible values, by determining the deviations of the throttle characteristics in the form of deviations of individual parameters, as well as through the analysis of deviations of the parameter complexes using mathematical models of the gas turbine engine. Building mathematical models is the most critical the stage of thermogasdynamic diagnostics of the gas turbine engine and is mainly determined by the correctness of the formulation of the equations included in the model. The number of diagnostic equations is determined by the classes of possible states of the GTE.

In a number of works for diagnostics of gas turbine engines, it is proposed to use complex parameters, which in analytical form relate several parameters to each other and thereby most fully characterize the working processes occurring in the engine. For example, in for the HPT it was proposed to use the ratio of the gas temperature behind the turbine TG to the oil pressure in the torque meter. Using similar parameters to control technical the state of the gas turbine engine in the course of bench tests, as well as in operating conditions can be very effective in assessing engine performance.

It is believed that the vibroacoustic diagnostics of a gas turbine engine is sufficiently informative. It is based on the general principles of recognizing the states of technical systems based on the initial information contained in the vibroacoustic signal.

The causes of vibration are cyclic processes that occur during the operation of the gas turbine engine (rotation of rotors, periodic loads, etc.). In turn, the vibration of the machine elements causes the ambient air to vibrate, that is, it serves as a source of acoustic noise. In some machines, for example, in aircraft gas turbine engines, a powerful source of acoustic noise is a gas jet, acoustic radiation from compressor blades, etc.

A change in cyclic processes will also entail a change in vibroacoustic processes, and hence their characteristics.

The reasons for the change in vibroacoustic characteristics can be imbalance of rotors, surging phenomena in an axial compressor, wear of blades in the flow path of an aircraft gas turbine engine, destruction of bearing assemblies, wear of gear teeth, misalignment of transmission shafts, wear of electric motor brushes, wear of moving joint parts, etc.

The characteristics of the vibroacoustic signal accompanying the operation of the gas turbine engine are used here as diagnostic signs.

At present, for aircraft engines, the general vibration level is a parameter that is subject to mandatory normalization and control by on-board instruments in flight. The effectiveness of vibration level control in aircraft gas turbine engines is proved by the fact that about a third of the detected engine malfunctions is the result of an assessment of their vibration state.

A deeper diagnosis is possible using spectral characteristics. However, obtaining these characteristics and their practical use is difficult due to the complexity of the equipment and diagnostic techniques. In addition, vibroacoustic methods require processing a large amount of statistical information. All this somewhat hinders the widespread use of these methods.

The use of tribodiagnostics methods is due to the fact that a fairly significant part of GTE failures is associated with a malfunction of friction units due to unacceptable wear. It is based on an assessment of the concentration and composition of wear products in the operating oil.

To implement this method, aviation technology and operating organizations must be equipped with recording and analyzing devices that allow detecting and trapping wear products, as well as quantifying the content, structure and chemical analysis of these products. For this purpose, the following are used: magnetic plugs for capturing particles; electrical signaling devices that are triggered when their electrodes are closed by particles; spectral analysis of oil; analysis of changes in the shape of particles, their surface; scattering and attenuation of the light beam when passing through the oil flow; analysis of changes in oil viscosity.

Along with the above methods of monitoring and diagnosing aviation gas turbine engines, the technical condition of critical units and engine parts, such as compressor and turbine blades, combustion chambers, discs, etc., is determined by optical control methods using baroscopes and endoscopes. These methods successfully identify a wide group of defects such as cracks, burnouts, warpage, corrosion, erosion, wear of contact surfaces, wear of labyrinth seal elements, carbon formation, etc.

The information content of the considered methods is very high and they have proven themselves well in operation.

One of the most informative methods for assessing the state of a gas turbine engine are methods for monitoring thermal parameters. Their main advantage is the ability to obtain information without significant disassembly of the engine.

However, thermal diagnostics involves the use of a wide range of expensive tools. For visual inspection, for parallel information retrieval, electro-optical converters are used.

Despite this, non-contact thermal diagnostics of gas turbine engines is very promising due to its high information content. It is important that the developed diagnostic tools make it possible to directly detect GTE defects and predict their development. Existing methods of processing infrared thermometry make it possible to predict specific faults.

At present, the use of thermal methods in operation is limited to monitoring the temperature at various points of the flow path and comparing it with permissible values. Thermal methods were more developed during bench tests of gas turbine engines.

Main diagnostic methods for gas turbine engines:

Thermal imaging (infrared thermography)

Tribominitoring (analysis of samples of aviation oils)

Endoscopy (photo and video documentation)

Vibroacoustic

Thermogasdynamic parameter

1.3. Diagnostics of gas turbine engines and their units by thermogasdynamic parameters

1.3.1. GTE malfunctions and their influence on the thermogasdynamic parameters of the engine

The parameters of the TGD are affected by malfunctions of the elements of the flow path, which change the geometry and dimensions of the parts, as well as malfunctions of the automatic control system of the engine. Such malfunctions include abrasive wear of compressor blades, an increase in radial clearances in compressors and turbines, deformation and partial destruction of compressor and turbine blades for various reasons, burnout of flame tubes of combustion chambers and turbine CAs, contamination and other deposits on the blades of compressors and turbines, etc. NS. Defects that do not lead to a change in the geometry of parts - cracks in blades, shafts, discs, bearing defects in the initial stage of development, etc., do not affect the THD parameters and cannot be detected by parametric control methods.

The degree of damage to the elements of the flow path and their nature depend on the conditions and service life of the engine. On the gas turbine engine of aircraft power plants, damage by foreign objects that enter the engine when the thrust reverse is turned on, when taxiing, testing engines, and improper use of anti-icing systems prevail. There is also a gradual deterioration in performance due to small accumulating changes in the elements of the flow path - wear, pollution, etc.

In helicopter gas turbine engines, there is intense abrasive wear of the compressors, damage due to the ingress of foreign objects [38], arising from the high concentration of dust under the rotor of the helicopter during takeoff and landing.

At the GTE of ground installations, along with other malfunctions, the phenomena of intensive pollution of the compressor or its abrasive wear are frequent, which is determined by the climatic conditions of the place of operation of the engine.

Parameter control is carried out in order to determine the state of the engine and diagnostics, i.e. determining the reason for changing the parameters. It should be borne in mind that a limited number of TGD parameters are measured on the aircraft, their changes at the time of monitoring are small, since faults should be detected at the initial stage of development.

Therefore, to obtain a reliable diagnosis, special methods of measuring, processing and analyzing parameters are required.

1.3.3. Changes in the state of the gas turbine engine during long-term operation

During operation, the engine, its systems and assemblies are

under the influence of many operational factors leading to gradual change in the parameters and performance of the engine (wear, "aging").

In a gas turbine engine, damage inevitably occurs in the form of wear of the seals of the flow path - the labyrinths of compressors and turbines, special layers of the working rings of compressors, inserts of the working rings of turbines, as well as small wear and contamination of compressor and turbine blades, etc. These changes, gradually accumulating, can lead to a decrease in engine thrust (power) to a critical value, at which its further operation becomes unacceptable due to non-compliance with flight safety requirements. A decrease in engine parameters to a critical value is characterized as a gradual failure. The operating time to failure depends on the intensity of damage accumulation, determined by the operating conditions of the gas turbine engine. It is known that up to 85% of early decommissioning of helicopter GTEs occurs due to gradual failures.

On aircraft gas turbine engines, the tendency to change the parameters is also manifested, although with a sufficiently large operating time. Thus, for ~ 30% of the (НК-8-2У) engine park, a stable change in parameters is observed at operating times over 4000 hours . On (Д-30КУ) engines, such changes are observed with operating hours of 3000 h.

Accumulating changes in the components of the gas-turbine engine flow path lead to a decrease in the efficiency of the units and the entire engine. This is manifested through a decrease in the rotational speed and engine thrust at a given mode work, i.e. given fuel consumption. On cruising flight modes

the decrease in thrust can be compensated for by an increase in fuel delivery.

However, in takeoff mode, it is impossible to eliminate the lack of thrust by increasing fuel consumption, since the throttle control is on the stop. A lack of takeoff thrust leads to a special situation in one of the most difficult flight phases - takeoff. For this reason, there have been aviation accidents. For example, in July 1999. when taking off from the Irkutsk airfield, the Ил-76ТД aircraft did not climb, rolled out of the runway and suffered an accident. One of the reasons for the accident was the lack of thrust of engines No. 3 and 4.

The thrust of a bypass engine (turbojet engine) is indirectly estimated by the rotor speed LP at a given operating mode. As the engine "ages", drops below the lower limit. They restore traction by increasing the fuel supply by adjusting the fuel automation. In this case, $n_{НД}$, так и $n_{ВД}$ и $T_{Г}$. increase. The limiting factor in the adjustment is the achievement of the upper tolerance limit for these parameters by the parameters nVD and TG. The tolerances are small, for example, on the D-30KU engine in takeoff mode, the parameters have tolerances $n_{НД}$ (± 2%), $n_{ВД}$ (+ 1% ÷ -0.5%). If the adjustment fails to restore the thrust, the engine is taken out of service for refurbishment.

1.4. Compressor malfunctions

Malfunctions of GTE compressors arise as a result of design and production shortcomings and the influence of operating factors, among which damage by foreign objects entering the flow path of the engine plays a significant role.

Damage to compressor blades by foreign objects is the most common cause of early engine decommissioning (EED). So, on engines НК-8-2У, НК -86 67% of all early engine replacements occur for this reason.

Damage occurs when pieces of ice, small stones, wire from the surface of parking areas, taxiways, runways get into the flow path, and sometimes foreign objects left inadvertently in the air intakes during maintenance. Most often, foreign objects get into the engine when starting and testing, taxiing, engaging the reverse thrust.

Types of blade damage: nicks (~ 70% of the total), dents, curvatures (~ 15%), nicks with tears, cracks and breaks of the ends of the blades (~ 10%), combinations of damage.

The frequency of damage depends on the layout of the control system on the aircraft - the height of the air intakes, the presence of thrust reverse. So on the Tu-154 aircraft, the 1st and 3rd engines are damaged 4 times more often than the 2nd, which is explained by the presence of thrust reverse on the extreme engines and a lower location of the air intakes.

In winter, damage is 2-3 times more frequent than in summer, due to the presence of ice spots on taxiways, runways and parking lots. It is possible that ice gets into the engine if the anti-icing system of the aircraft and the engine is used incorrectly, when ice formation on the wing and air intakes is allowed, and when the anti-icing system is subsequently turned on, ice breaks off and gets into the engine.

The most frequently damaged blades of the 1st stage (~ 45% of the total number of damages). More than 65% of all injuries are in the upper third of the scapula, and in the root part ~ 2%.

On helicopter gas turbine engines, the likelihood of damage by foreign objects is very high. This is facilitated by the air flow from the main rotor, which lifts small stones and other objects from the surface of the take-off area together with dust. In flight, hail, birds, ice may get into the engine if the anti-icing system is ineffective.

Damage to blades by foreign objects in GTEs of ground-based installations is also the main problem. The reasons for the damage are the ingress of ice from the inlet device of the control system during improper use or malfunction of the anti-icing system and foreign objects (bolts, nuts, etc.) left in the inlet device during maintenance.

Damage to the blades can lead to cracks and destruction of the blades. The most dangerous is a crack in the root part. On most engines, damage is not allowed in this part of the blades; on the remaining parts of the blades, tolerances are set for the depth of nicks, their number on the blade, in the compressor stage. Damage to the blades is detected by visual-optical methods during maintenance. Influence on TGD parameters is insignificant. Only in case of damage that caused a change in the geometry of the blades - partial destruction, curvature, air consumption decreases, the degree of pressure increase, efficiency. compressor decreases thrust (power) of the engine. Such an event can be detected by a decrease in air pressure behind the compressor, an increase in the temperature of gases (TG) and an increase in the slip of the rotors (on the turbojet engine).

Abrasive wear of parts of the gas-turbine engine flow path. Is one of the most common types of damage to some types of engines, including helicopter engines, stationary power plants. In the first case, intensive wear is caused by a high concentration of dust in the air flow under the rotor during takeoff from unpaved airfields, in the second - by long-term operation in dusty air, albeit with a lower concentration.

Abrasive wear occurs as a result of the interaction of solid dust particles with the surface of the part. Moving at high speed along the flow path of the engine, abrasive particles cause wear of the compressor blades, special layers of working rings, labyrinth seals. There are only signs of wear on the turbines.

In general, the amount of wear depends on many factors: dust concentration, dispersion and mineralogical composition of particles, duration of operation in dusty air, material compressor blades. The greatest wear is observed during the operation of the in areas with sandy soil. The state of gas turbine engines of power plants is strongly influenced by weather and climatic conditions, in particular such a meteorological phenomenon as a dust storm. The operation of engines is often impossible to stop even in very dusty air, for example, it is impossible to stop the operation of engines of gas compressor units of main gas pipelines.

In GTE axial compressors, the rotor blades wear out the most. The degree of wear increases towards the last stages, which is explained by an increase in the volume concentration of particles in the flow due to its compression and an increase in the number of particles due to crushing of large grains of sand.

Wear is observed over the entire height of the first stage blade along the leading and trailing edges. In the last stages, due to the centrifugation of particles, more peripheral parts are damaged. The trailing edge of these blades is more damaged than the front.

The guide vanes wear out less than the workers, and if the latter wear practically the same within a stage, then the guide vanes can have unequal wear, which is explained by the peculiarities of air entry into the engine at different power plants. Increased wear of the stator blades can occur in various zones of the engine, both along the compressor length and along the circumference of the stages.

In some cases, abrasive wear can be significant. Thus, on TB-2-117A engines, 30% of engines supplied for early overhaul are taken out of service due to abrasive wear of the compressor blades. When operating helicopters on sandy sites, the compressor's maximum wear is achieved with an engine operating time of 800-1000 hours.

An effective means of combating abrasive wear is the use of dust filters on the air intake of engines. However, dust filters reduce the power of the control system, which limits their use in helicopters. In stationary power plants, inlet cleaning devices are constantly switched on and significantly reduce engine damage even in extreme weather and climatic conditions. For example, during dust storms in the deserts, is the only engine protection against rapid failure.

The wear of the blade of the working and guide vanes, an increase in the radial clearances in the impellers leads to a decrease in the air consumption (G), increase the degree of pressure (π *), and a decrease the compressor efficiency, an increase in specific fuel consumption, an increase in gas temperature.

The maximum engine power and gas dynamic stability margin are reduced.

Due to the strong influence of abrasive wear on the operational properties of the gas turbine engine, it is urgent to timely determine the dangerous damage to the compressor, which can be carried out by the assessment of the gas turbine engine parameters. The degree of compressor wear can be assessed by a decrease in air pressure, an increase in the slip of rotors on a gas turbine engine with a twin-shaft compressor, increase in gas temperature.

Compressor fouling is present on all GTEs during long-term operation, but the degree of fouling depends on the operating conditions.

On engines of aircraft of 1 - 3 classes, during long-term operation, a dark coating appears on the fan blades and 1-st compressor stages. This leads to a decrease in engine thrust. At maximum mode, the rotor speed can decrease by ~ 0.5%, which is significant, taking into account the tolerance for this parameter (± 2%).

The most susceptible to the appearance of contamination are the compressors of gas turbine engines of power plants, in particular, engines, on which a decrease in power for this reason can reach 15%.

Pollution is caused by the presence of fine dust, pollen and flying seeds of plants, insects, and industrial emissions in the air. Fine dust contributes to the condensation of water vapor in the air stream at high humidity and sufficiently low temperatures. Contamination is also facilitated by the ingress of vapors and small drops of oil into the flow path from the front support of the compressor rotor and due to leaks in the external oil system of the control system.

A mixture of fine dust and other particles with moisture settles on the surfaces of the compressor parts and gradually compresses to form a hardened oily crust. Deposits are mainly formed on the blades. The thickness of deposits in the first stages can reach several millimeters. Their strength and hardness are quite high, the surface is rough. The blade profile is strongly distorted. Intense pollution spreads to about 6 first stages. The deposits on the rotor blades are significantly less than on the stator.

The most intense pollution of the flow path occurs in the summer period, however, in the rest of the year this phenomenon occurs due to meteorological phenomena such as inversions, in which the source of pollution is the release of the products of the operation of the power plant itself into the atmosphere.

Contamination of the gas-turbine engine flow path leads to a decrease in consumption air, pressure increase and efficiency, as a result of which the engine power is reduced, which can be very significant. Removal of deposits is carried out by special methods of cleaning the flow path, mainly by washing with detergent solutions.

Evaluation of the degree of contamination of the engine flow path and the quality of its cleaning is possible only by monitoring the THD parameters, their deviations from the base (initial) values. The most sensitive parameters in this case, as in other compressor malfunctions, are the air pressure behind the compressor, the "slip" of the rotors and the temperature of the gases in front of (behind) the turbine.

Destruction of compressor blades. A significant number of GTE failures are associated with the destruction of compressor blades, which can be caused by design and production defects and operational factors.

Structural and production reasons - insufficient structural strength of blades, poor-quality workmanship (material defects, high residual stresses, surface burns during machining, dimensional deviations from the drawing, etc.) lead to the appearance of fatigue cracks with subsequent destruction.

The operational reasons for the destruction of the blades are often caused by damage to the blades by foreign objects. It is known that when the nick is located in the high stress zone, i.e. in the region of the vibration node, a fatigue crack always starts from the point of damage.

Damage (breakage, curvature) of the blades can also occur as a result of compressor surging, exceeding the permissible engine operating time at maximum mode or at a mode higher than the permissible for the given flight conditions. Damage to the blades is possible if the maintenance rules are violated, for example, when trying to start the engine if the rotor blades freeze to the engine housing.

The prevention of blade breakage is achieved by appropriate preventive measures - visual and instrumental monitoring of the condition of the blades, observance of the established modes and operating time at high modes, observance of the rules for preparing the engine for start-up, etc. After the engine is turned off, the rotor "stick out" is checked in order to identify possible hindered rotation of the rotor, which, along with others, can be caused by deformation of the rotor blades and their contact with the stator part.

Destruction of the rotor blades causes engine failure, can lead to damage to other elements of the power plant, systems and the aircraft airframe. Signs of destruction of the blades in flight are the occurrence extraneous noise in the engine, increased vibration, an increase in the gas temperature in front of the turbine above the permissible for this mode. Surge may occur.

In some cases, partial destruction of the blades remains unnoticed due to the absence of pronounced external signs. In these cases, damage can be detected by analysis of TGD parameters. Diagnostics will also prevent the consequences of destruction that may arise due to subsequent destruction of parts of the flow path, caused by partial destruction of the blade.

A decrease in the compressor efficiency with the destruction of the blades causes a decrease in the thrust (power) of the engine, a decrease in the high pressure rotor speed at a given value of $n_{НД}$, an increase in fuel consumption and gas temperatures.

Often during the operation of the engine, the destruction of a special layer of the compressor working rings occurs. It is also detected by a change in the TGD parameters.

1.5. Combustion chambers malfunctions

During operation, cracks and deformations of thermal origin, fatigue cracks, cracks along welds, local overheating, melting and cracking of the material at the secondary air supply holes, and wall burnouts in various zones can occur on the flame tubes of combustion chambers during operation.

The occurrence and development of malfunctions of the combustion chamber depends on the design features of the flame tubes and fuel injectors, as well as on a number of operational factors. The latter include the quality of the fuel used, compliance with the required engine starting modes, warming up after starting in the low gas mode, adhering to the established rules for bringing the engine to higher modes and operating in these modes, cooling the engine in low gas mode before shutting down.

Poor fuel quality leads to carbon formation on the walls of the flame tubes, coking or clogging of the fuel injectors. Carbon deposits cause changes in the cooling conditions of the sections of the chamber, their overheating and burnout. The formation of coke on the parts of the injectors, their clogging leads to a deterioration in the fuel spray, distortion of the shape of the combustion flame, deviation of the flame from the axial direction of the chamber, which leads to local overheating and burnout of the walls of the flame tubes.

Cracks in the flame tubes arise as a result of vibration processes due to the design features of the combustion chamber, and also due to repeated thermal stresses arising in parts of complex shapes during rapid temperature changes during engine starts and in transient operating modes. The higher the rate of temperature change, the higher the thermal stresses and the likelihood of thermal cracking. On all gas turbine engines of any purpose, the operating rules provide for warming up in low gas mode for 5 minutes and warming up in intermediate modes before reaching maximum modes. Before turning off the engine, cooling is required ~ 3 ÷ 5 min on low gas. Failure to comply with these rules leads to "heatstroke" and cracking of the flame tubes. The temperature rise during engine start and in transient modes is determined by the setting of the automatic start-up and throttle response.

Cracks in the components of the combustion chamber can lead to their partial destruction, which necessarily leads to secondary damage in the engine. Pieces of the flame tube that have fallen out damage the turbine blades or discs and cause increased engine vibrations.

Disruption of the combustion chamber associated with a malfunction of the fuel injectors, burnout of the flame tube, leads to deformation of the temperature field behind the combustion chamber, a decrease in the turbine power, a decrease in the efficiency of the combustion chamber (η_{Γ}), and an increase in the resistance of the combustion chamber (σ_{Γ}). Fuel consumption increases, temperature of gases, "slip" of rotors.

1.6. Turbine malfunctions

A common malfunction of GTE turbines, which affects the gas-dynamic parameters, is an increase in the radial clearance between the impeller blades and CA inserts, due to wear of the inserts, wear and tear of the combs of the shroud flanges of the working rings.

The wear of the shroud flanges and inserts can be due to the fact that in transient modes - starting, stopping, a sharp change in the operating mode due to the different rate of change in the temperature of the body and working rings, the radial clearance decreases and can reach zero and even negative values. Consequently, the amount of wear is influenced by the operating conditions of the engine.

The radial clearance between the inserts and the impeller of the 1st stage of the turbine of the НК-8-2У engine due to wear can reach 2 ÷ 2.5 mm with the tolerances according to the drawing 0.8 ÷ 1 mm.

Quite often, burnout and melting of the AC blades occur on a gas turbine engine due to a general or local increase in the temperature of the gas flow above the permissible value.

A general increase in temperature is usually associated with improper operation of the fuel equipment, for example, when starting the engine, at maximum operating modes, with an unstable combustion chamber operation time or unstable compressor operation (pumping). It is known that when the engine is pumping, the gas temperature rises so intensively that all blades can be burnt within 15–20 s. Failure to comply with the time limits for operation at maximum mode and on mains also leads to overheating of the turbine. The limitation of the operating time on the MG is due to the fact that the turbine cooling conditions deteriorate due to a decrease in the air pressure behind the compressor. Malfunctions of the combustion chamber, including "flaring" of nozzles due to coking or clogging, partial destruction and burnout of the flame tubes lead to damage to the HP turbine blades from overheating due to an increase in the unevenness of the temperature field. Most often, when the turbine overheats, burnout or melting of the blades of the SA of the HP turbine takes place.

Destruction of turbine blades is a rare but very dangerous malfunction. The reasons for the destruction can be design and production shortcomings - insufficient fatigue strength, high level of alternating stresses, disadvantages of machining, as well as wear of the working edges of the shroud flanges during operation and an increase in vibration loads in connection with this.

Thermal fatigue of the blades occurs due to a large number of starts and stops of the engine, multiple changes in their operating mode. In transient conditions, the leading and trailing edges of the blades are subjected to sharper temperature changes compared to the middle part, as a result of which significant thermal stresses arise in the edges. With the accumulation of heating and cooling cycles, cracks (low-cycle fatigue) can occur in the blade edges, as well as in the tool joint. In this case, the main factor of damage to the blades is not the total operating time of the engine, but the number of temperature change cycles and the intensity of transient processes.

Destruction of turbine blades can occur due to erosion-corrosion damage. Salts of alkali metals entering the engine (together with dust and fuel combustion products) under high temperature conditions destroy the upper surface layer, which contributes to the adsorption of sulfur on the surface. As a result, during long-term operation, metal sulfidation occurs, leading to its destruction.

The cause of destruction can be the ingress of foreign objects on the working blades, most often elements of destroyed parts upstream units of the engine flow path, leading to the appearance of nicks, material tears, followed by the development of a fatigue crack.

An increase in the clearances in the flow path of the turbine, burning of the blades of the AC and RK, breakage of the blades lead to a decrease in the efficiency of the turbine, its power, and a change in the power balance on the compressor-turbine shaft. The speed regulator, in an effort to maintain the set speed and restore the balance of power, increases the fuel supply. The gas temperature rises in front of and behind the turbine. On the turbofan engine, the "slide" of the rotors increases.

1.7. GTE condition monitoring by thermogasdynamic parameters

1.7.1. GTE parameters control tasks

The control of the parameters of the GTE operation is carried out when testing the engines during pre-flight preparation, when performing routine maintenance, the crew constantly monitors the parameters by instruments during the flight. During the entire flight, the parameters are automatically recorded by the onboard flight information recording facilities.

Control of parameters during pre-flight preparation and by the crew in flight is an express control and is designed to detect the limiting state of the engine. The measured parameters are compared with their maximum permissible values. If the checked parameters (gas temperature, rotor speed, parameter characterizing

thrust), go beyond the limits established by the operating manual for this type of engine, the aircraft is not allowed to fly until the reasons are clarified and the malfunctions are eliminated. If the parameter exceeds the limit limits during flight, the engine is turned off.

On modern aircraft (Il-96, Tu-204), information on the parameters of the engines (PS-90A) is displayed by the ACS on the screens of the integrated information signaling system. Several types of circular and linear scales are used to represent information. The current value of the parameter can be determined either by "scale" counting, or by reading its digital value in special cells located under the scales.

On the scales $n_{НД}$,$n_{ВД}$, $T_Г$ there are red marks corresponding to the limiting values of the parameters. When the parameter is within the normal range, the marks on the vertical scales and the number in the cell are highlighted in green. When the parameter reaches the limit value, the color of the corresponding vertical lines and the number in the cell changes to red.

The information obtained when testing engines during routine maintenance and obtained when decoding the recordings of on-board recorders is used to assess the condition of the engines - is it operational or inoperative, as well as for predicting state changes.

Methods for assessing the state of GTE by TGD parameters are based on comparing deviations of parameters from their base values with technical standards for these deviations.

The parameters of the engine in its initial state are taken as the basic ones, that is, the parameters obtained during acceptance tests at the plant or in the first hours of its operation on the aircraft. Comparison of the current values of the parameters obtained from operation with the basic values of the parameters is carried out using the throttle characteristics.

Flight information data obtained by means of on-board registration means are subjected to statistical processing in order to determine deviations of parameters from their values in the first flights on a given aircraft. The tendency of changes in parameters (trend) is also determined, the rate of these changes can serve as a sign of changes in the state of the engine and makes it possible to make predictions.

When implementing any method for monitoring the state of the engine by TGD parameters, complex tasks arise:

- assignment of tolerance for deviation of parameters;
- determination of the magnitude of deviations of the parameters from the basic values with the smallest errors.

Tolerances for deviations of parameters can be assigned from the conditions:

- the ability to detect engine malfunctions at an early stage of development;
- ensuring the specified safety margins, stability, reliability of the diagnostic object;
- ensuring the operational properties of the engine.

Detecting faults at an early stage is necessary to prevent their development and the occurrence of repeated damage. For example, burnout of the blades of the turbine nozzle apparatus should be detected as early as possible, the presence of this defect indicates a large inappropriate temperature field in front of the turbine due to malfunctions in the combustion chamber or other cause of turbine overheating, which can further lead to its destruction with unpredictable consequences. "Large" defects are recognized by external signs - poor engine start, metal deposits on the surface of the blades of the last stage of the turbine, the presence of extraneous sounds when the rotor is turning, etc. But it is dangerous to allow engine damage to such a degree, it is necessary to identify defects as early as possible.

The deviations of the parameters from the basic values for small defects are small and their detection and estimation of the value are possible with a sufficiently accurate determination of the initial values of the parameters and their values in the course of subsequent operational tests.

The baseline values are determined by a sufficiently accurate construction of the engine throttle characteristics in its initial state and the determination of the average static value of the parameters based on the results of the first flights of the engine installed on the aircraft.

The assignment of tolerances for parameters, based on the condition of ensuring strength, reliability, stability, involves limiting the maximum values of the gas temperature, the rotational speed, the degree of pressure increase. the upper values of the parameters are due to the margin of safety of the turbine blades, the margin of gas-dynamic stability, etc.

The condition for ensuring the operational properties of the gas turbine engine involves determining the permissible decrease in engine thrust (δP) at various stages of flight, including takeoff.

Taking into account the last two conditions, the control of the engine condition during ground testing is carried out in several operating modes and, without fail, on takeoff, for which the upper and lower tolerances for the parameters are set.

Along with solving the problems of monitoring the state of the engine, measuring the TGD parameters and assessing their deviations from the base values allows solving the problems of diagnostics, i.e. determine the reason for changing the parameters, install a faulty motor unit.

Measurement and analysis of GTE parameters is also performed:

- when adjusting the engine in operation, for example, when adjusting the compressor mechanization devices, rotor speeds, etc.;
- to assess the degree of change in individual engine components in cases where the nature of the malfunction is known. For example, in case of intensive compressor pollution, it is necessary to assess the amount of engine power reduction and evaluate the efficiency of the technological process of restoring the compressor state (flushing or cleaning).

1.8. The principles of diagnosing a gas turbine engine by TGD parameters

Technical diagnostics is the process of determining the technical the state of the object being diagnosed with a certain accuracy. The use of TGD parameters as carriers of diagnostic information makes it possible to assess the state of the engine not only as "efficient" or "Inoperative", but also to determine the place of the malfunction (localization of the defect). In this case, according to the information carried by the TGD parameters, with the help of mathematical models of the diagnostic object, the causes of the malfunctioning state are determined. The main tasks in this approach to diagnostics are the construction of an adequate model of the diagnostic object, the choice of the most informative measured parameters, etc.

The condition of engine elements is determined by a certain set of malfunctions: erosion, corrosion, pollution, formation of carbon deposits and other deposits, damage by external objects, wear of seals, melting or deformation of hot part parts, etc. Faults have different localization and magnitude and, accordingly, lead to a change in the main characteristics and parameters of the engine - rotor speeds, fuel consumption, temperature and pressures of air and gas, thrust or engine power, etc. Some of these parameters are measured by standard instruments installed on the aircraft, and with the help of these instruments it is possible to determine the presence of malfunctions.

Due to the variety of possible malfunctions and their sizes, it is impossible to localize the malfunction with a limited number of devices. Therefore, the task of diagnostics using TGD parameters is not a search for a specific malfunction, a faulty element, but nodal diagnostics, i.e. identification of a faulty node with subsequent identification of a malfunction in this node by other diagnostic methods.

Malfunctions cause changes in the characteristics of engine components: compressor performance, degree of air pressure increase, degree of pressure drop in turbines, effective areas of nozzles, unit efficiency, etc. Parameters directly related to faults are called primary or state parameters in diagnostic theory.

The state parameters are functionally related to the parameters of the engine's working process - temperatures, air and gas pressure, rotor speeds, etc. All these parameters are called secondary, so how they are related to malfunctions through changes in the characteristics of the nodes, i.e. through the primary parameters. Some of the secondary parameters are measured and referred to the category of "diagnostic".

Thus, the measured parameters are dependent variables, the absolute values and changes of which are determined by changes in the primary, performance characteristics. If defects lead to a deterioration in the characteristics of engine components, which, in turn, causes a change in the measured parameters, then these changes can be used to assess the state of the engine components (nodes). This approach to diagnosing a gas turbine engine is shown in Table 1.1.

Malfunctions • Erosion • Corrosion • Deposits • Damage by foreign objects • Increased clearances • Burning • Bending of the blades • Destruction	Lead to	Deterioration of node characteristics • compressor efficiency • The area of the turbine nozzle • turbine efficiency	Lead to	Changing the measured parameters • Rotor speed • Fuel consumption • Gas temperature • Air pressure • Power

Table. 1.1. Diagram of a method for diagnosing a gas turbine engine by TGD parameters

To implement this approach, it is necessary to establish a relationship between changes in primary variables and measurable dependent (secondary) parameters. This task is solved by drawing up and solving a mathematical model of the product.

1.9. Influence of GTE malfunctions on the characteristics of engine units

Influence of malfunctions of axial compressors on their characteristics Most types of malfunctions of the flow path of axial compressors, including abrasive wear of blades of impellers, contamination of blades, an increase in clearances between blades and working rings, etc., Lead to a change in the geometry of damaged parts and, therefore, affect the kinematics of the flow and the parameters of the air state in the compressor.

Let us consider, in particular, the effect of abrasive wear on the operation of a stage and the entire compressor.

Abrasive wear occurs as a result of the interaction of solid particles in the flow with the surface of the part and leads to a change in the shape of the profile of the scapula, mainly in its front and rear parts. As a result, the curvature (bending angle) of the profile decreases and, as a consequence, the angle of flow exit (Fig. 1.2).

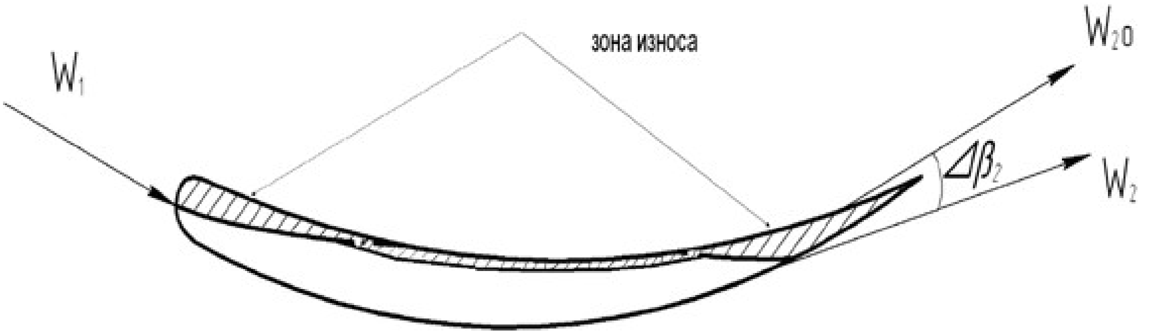


Fig. 1.2. - Diagram of the change in the flow units during blade wear: W_1, W_2- relative flow rates at the inlet and outlet; W_{20} is the relative exit speed before the profile change; $\Delta\beta_2$ - change in the angle of flow

When the compressor blades become dirty, they also change profile, deformation of the velocity triangles, reduction of the pressure head of the stage. The difference from the case of wear is that deposits are formed mainly on the stator blades and the kinematics of the flow in the guide vane and at the inlet to the impeller changes, but as a result, the parameters of the compressor operation in terms of air flow, the degree of pressure increase and its efficiency will change downward.

An increase in radial clearances due to wear and destruction of sealing rings, wear or partial destruction of the airfoil blades of the impeller leads to a decrease in the efficiency of the stage, and, consequently, of the compressor due to the end overflow of air.

Significant radial clearances that can form, for example, at the last stages of the lead to a decrease not only in the efficiency of the stage, but at the same time in its internal work due to a decrease flow swirls in end sections. This in turn reduces the compressor head.

Compressor operating parameters have a direct impact on the performance of the entire engine. Since a direct assessment of the change in the compressor efficiency and air consumption is impossible, the state of the compressor, as well as of other engine components, is assessed indirectly through the measurement of temperature, air pressure, gas, rotor speed, etc. For these purposes, the parameters of the engine units are included in the mathematical model of the engine.

Conclusions for part 1

From this part, we learned about the methods of technical diagnostics, basic concepts, terms and definitions. We consider principles of diagnostics of gas turbine engines and their units by thermogasodynamic parameters. Consider influence of GTE malfunctions on the characteristics of engine units.

PART 2

STANDARD ENGINE MODEL

2.1 Short description

Prototype - Turboshaft aircraft engine TB3-117.

Developer: S.P. Izotov

Country: USSR

Start of development: 1965

State tests: 1972

Entered service: 1977

The development of the TB 3-117 turboshaft engine for the Ми -24 helicopter began at the (ОКБ им. В.Я.Климова) under the leadership of S.P. Izotov in 1965. For the first time in the domestic engine building, it was decided to use on the engine a titanium compressor rotor welded from separate disks by electron beam welding, compressor blades and guide vanes made of titanium alloy, obtained by cold rolling, small-sized contact graphite seals of oil cavities. Compared to TB2-117, the new engine turned out to be 30% more powerful with smaller dimensions and weight. In 1972, he passed the state tests. In the same year, its serial production began at the Zaporozhye plant «Моторостроитель».

Design features:

- axial 12-stage compressor with adjustable inlet guide vanes and guide vanes of the first four stages;
- annular direct-flow combustion chamber;
- axial 2-stage compressor turbine;
- axial 2-stage free turbine;
- an exhaust pipe with a flow turn by 600;
- hydromechanical (on the first modifications) and electro-hydromechanical (on the latest modifications) regulation and control system;
- a dust protection device can be installed at the compressor inlet.

Electronic components are used in the control system. The engine runs on aviation kerosene grades T-1, TC-1, PT. The oil system uses (Б-3В) synthetic oil.

The TB3-117 engine is one of the best in the world in terms of efficiency in its class, which was achieved by the high efficiency of the units (compressor - 86%, compressor turbine - 91%, free turbine - 94%). It is successfully operated in marine, arctic and tropical climates.

TB3-117 is produced in large series in various modifications. By 2000, more than 23,500 engines were manufactured. It was exported together with helicopters to 60 countries of the world. During the production process, the engine was constantly improved. As a result, the resource before the first overhaul was brought to 3000 hours.

TV3-117BMA-Ф - experimental for Ми-28N, Ka-50, Ka-52. Differs in an electronic-hydromechanical system of regulation, control and monitoring. Takeoff power increased to 2500 hp, in emergency mode - up to 2800 hp.

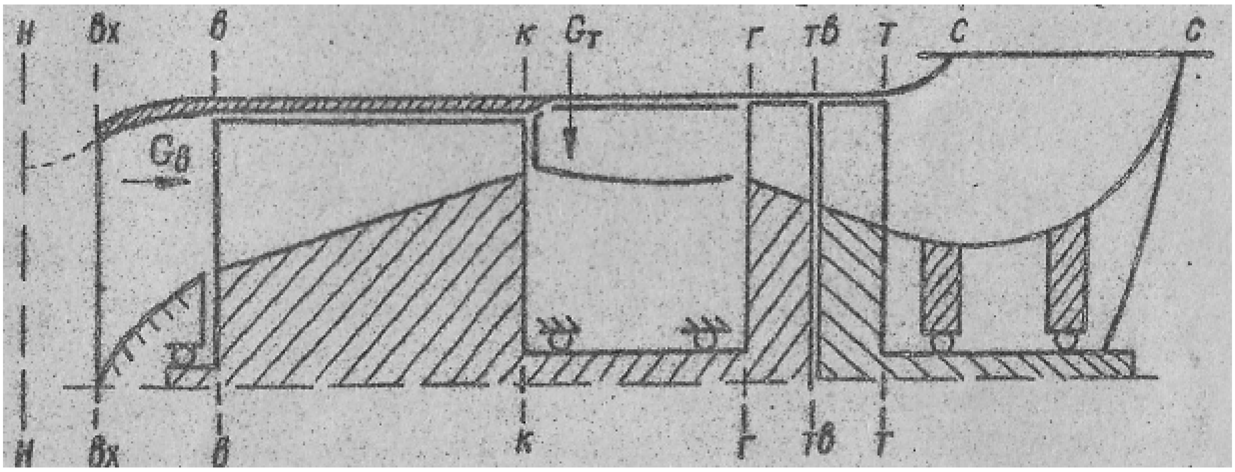


Fig. 2.1 engine diagram with designation of sections of the flow path

2.2 Thermodynamic calculation of the engine

ТВ3 – 117ВМА – Ф

Engine power	$P := 137293.1$ Вт
Bypass ratio	$m := 0$
Pressure ratio	$\pi^*_{c\Sigma} := 9.43$
Equivalent power	$N_e := 1660000$ ВТ
Gas temperature	$T^*_g := 1253$ К

Atmospheric constants and flight conditions

$H := 0 \qquad T_{\text{н}} := 288 \text{ К} \qquad R := 287 \qquad k := 1.41$

$V := 0 \qquad P_{\text{н}} := 101300 \text{ Pa} \qquad R_g := 288 \qquad k_g := 1.33$

2.2.1 Determination of air parameters in engine section В-В

Air temperature and pressure at altitude H=0

$$T^*_{\text{н}} := T_{\text{н}} + \frac{k-1}{k} \cdot \frac{V^2}{2R} = 288 + \frac{1.41-1}{1.41} \cdot \frac{0^2}{2 \cdot 287} = 288.0 \qquad \text{К}$$

$$P^*_{\text{н}} := P_{\text{н}} \cdot \left(\frac{T^*_{\text{н}}}{T_{\text{н}}}\right)^{\frac{k}{k-1}} = 101300 \cdot \left(\frac{288.0}{288}\right)^{\frac{1.41}{1.41-1}} = 101300.0 = 101300 \qquad \text{Pa}$$

$$T^*_{inlet} := T^*_{\text{н}} = 288 \qquad \text{К}$$

Full pressure recovery factor $\sigma_{inlet} := 0.98$

$$P^*_{inlet} := P^*_{\text{н}} \cdot \sigma_{inlet} = 101300 \cdot 0.98 = 99273.0 = 99273 \text{ Pa}$$

2.2.2 Determination of air parameters behind the compressor - section К-К

Efficiency compressor stages $\eta^*_{st} := 0.88$

Efficiency compressor

$$\eta^*_c := \frac{{\pi^*_{c\Sigma}}^{\frac{k-1}{k}} - 1}{{\pi^*_{c\Sigma}}^{\frac{k-1}{k \cdot \eta^*_{st}}} - 1} = \frac{9.43^{\frac{1.41-1}{1.41}} - 1}{9.43^{\frac{1.41-1}{1.41 \cdot 0.88}} - 1} = 0.8374 = 0.837$$

Efficient work of air compression in the compressor

$$L_c := \left[\frac{k}{k-1}\cdot R\cdot T^*_{inlet}\cdot\left(\pi^{*}_{c\Sigma}{}^{\frac{k-1}{k}}-1\right)\cdot\frac{1}{\eta^*_c}\right] = 312395.811\ \frac{J}{kg}$$

Air temperature and pressure behind the compressor

$$T^*_c := T^*_{inlet} + \frac{k-1}{k}\cdot\frac{L_c}{R} = 604.51 \quad К$$

$$P^*_c := P^*_{inlet}\cdot\pi^*_{c\Sigma} = 99273\ Pa.43 = 936144.0 = 936144 \quad Pa$$

2.2.3 Determination of parameters at the outlet from the combustion chamber -section Г-Г

Recovery coefficient of total pressure in the combustion chamber $\sigma_{c.ch} := 0.98$

Pressure before turbine

$$P^*_g := P^*_c\cdot\sigma_{c.ch} = 936144\cdot 0.98 = 917421.0 = 917421 \quad Pa$$

Average heat capacity of gas in the combustion chamber

$$C_{average} := 878 + 0.208\cdot\left(T^*_g + 0.48\cdot T^*_c\right) = 1198.978 \quad \frac{J}{kg\cdot К^2}$$

Combustion efficiency $\eta_{c.e} := 0.99$

Calorific value (теплотворность) $H_u := 43\cdot 10^6$

$$g_t := \frac{C_{average}\cdot\left(T^*_g - T^*_c\right)}{\eta_{c.e}\cdot H_u} = 0.018$$

Average ratio of excess air in the combustion chamber at $l_0 := 14.85$

$$\alpha := \frac{1}{g_t\cdot l_0} = \frac{1}{0.018264621036700162\cdot 14.85} = 3.687 = 3.687$$

2.2.4 Determination of gas parameters behind the high-pressure turbine - section Тв-Тв

Air bleeding for cooling turbine parts $g_{cool} := 0.04$ and mechanical efficiency of the turbine $\eta_{м} := 0.985$

$$L_t := \frac{L_c}{(1 + g_t) \cdot (1 - g_{cool}) \cdot \eta_{м}} = 324442.01 \qquad \frac{J}{kg}$$

Turbine efficiency $\eta^*_t := 0.9$ and find the temperature and pressure behind the turbine

$$T^*_t := T^*_g - \frac{k_g - 1}{k_g} \cdot \frac{L_t}{R_g} = 1253 - \frac{1.33 - 1}{1.33} \cdot \frac{324442.0095651506}{288} = 973.5 = 973.5 \quad K$$

$$P^*_t := P^*_g \cdot \left(1 - \frac{T^*_g - T^*_t}{T^*_g \cdot \eta^*_t}\right)^{\frac{k_g}{k_g - 1}} = 291097.908 \qquad Pa$$

Turbine pressure drop

$P^*_{t.c} := 1.1 \cdot P_{н} = 111430$

$P^*_t = 291097.908$

$\lambda_{gas} := 0.5$

$\eta^*_{free.t} := 0.89$

$$\pi_{т} := \left[\frac{1}{1 - \frac{1}{\eta^*_t}\left(1 - \frac{T^*_t}{T^*_g}\right)}\right]^{\frac{k_g}{k_g - 1}} = 3.152$$

Free turbine operation

$$L_{free.t} := \frac{k_g}{k_g - 1} \cdot R_g \cdot T^*_t \cdot \left[1 - \left(\frac{P^*_{t.c}}{P^*_t}\right)^{\frac{k_g - 1}{k_g}}\right] \cdot \eta^*_{free.t} = 213205.194$$

$$T^*_{gas.t} := \left(T^*_t - \frac{k_g - 1}{k_g} \cdot \frac{L_{free.t}}{R_g}\right) = 789.818 \quad K$$

2.2.5 Gas velocity and static parameters of gas behind the turbine

$$c_t := \lambda_{gas} \cdot \sqrt{2 \cdot \frac{k_g - 1}{k_g} \cdot R_g \cdot T^*_{gas.t}} = 167.987$$

$$T_t := T^*_{gas.t} \cdot \left(1 - \frac{k_g - 1}{k_g + 1} \cdot \lambda_{gas}{}^2\right) = 761.852$$

$$P_t := P^*_{t.c} \cdot \left(1 - \frac{k_g - 1}{k_g + 1} \cdot \lambda_{gas}{}^2\right) = 107484.517$$

$P_t = 107484.517$

$P^*_t = 291097.908$

2.2.6 Determination of the parameters of the gas flow at the outlet of the jet nozzle

Differential pressure in the jet nozzle of the inner loop

$$\pi_{out} := \frac{P_t}{P_н} = \frac{107484.51716738199}{101300} = 1.061 = 1.061$$

$T^*_{gas.t} = 789.818$

$$\pi_{out.cr} := \left(\frac{k_g + 1}{2}\right)^{\frac{k_g}{k_g - 1}} = \left(\frac{1.33 + 1}{2}\right)^{\frac{1.33}{1.33 - 1}} = 1.851 = 1.851$$

The gas velocity and temperature are determined by the following formulas

$\varphi_{out} := 0.985$

$$C_{out} := \varphi_{out} \cdot \sqrt{2 \cdot \frac{k_g}{k_g - 1} \cdot R_g \cdot T^*_{gas.t} \cdot \left[1 - \left(\frac{P_н}{P^*_{t.c}}\right)^{\frac{k_g - 1}{k_g}}\right]} = 203.9 \qquad \frac{м}{с}$$

$P_{out} := P_н$

$$T_{out} := T^*_{gas.t} - \frac{k_g - 1}{k_g} \cdot \frac{C_{out}{}^2}{2 \cdot R_g} = 771.908 \quad К$$

Specific power transmitted to the propeller from the turbine

$g_t = 0.018$

$L_{spec} := L_{free.t}$

$N_{spec} := L_{spec} \cdot (1 + g_t) = 217099.109$

Specific fuel and air consumption and specific effective power at the output shaft

$$C_{spec} := \frac{3600 \cdot g_t \cdot (1 - g_{cool})}{N_{spec}} = 0$$

$$g_t := \frac{C_{average} \cdot (T^*_g - T^*_c)}{\eta_{c.e} \cdot H_u} = 0.018$$

Air consumption through TSE (TurboShaft Engine)

$$G_{consump} := \frac{N_e}{N_{spec}} = 7.646$$

$N_{spec} = 217099.109$

Internal engine efficiency

$$\eta_e := \frac{L_{spec}}{g_t \cdot H_u \cdot (1 - g_{cool})} = 0.283$$

$$G_т := 3600 \cdot G_{consump} \cdot (1 - 0.04 - 0) \cdot g_t = 482.652$$

2.3 Gas-dynamic calculation of the engine

2.3.1 Determination of the dimensions of the section at the inlet to the compressor B-B

We accept the value of the axial air velocity and the peripheral (окружная) speed of the blades according to the recommendations

$C_{1a} := 180 \ \frac{м}{с}$ $\qquad$ $u_{1end} := 300 \ \frac{м}{с}$

Find the transmitted (приведенную) speed

$$\lambda_{1a} := \frac{C_{1a}}{\sqrt{2 \cdot \frac{k \cdot R \cdot T^*_{inlet}}{k+1}}} = 0.579 \qquad \frac{C_{1a}}{18.3 \cdot \sqrt{T^*_{inlet}}} = 0.58$$

Relative current density

$$q_{.\lambda 1a} := \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \cdot \lambda_{1a} \cdot \left(1 - \frac{k-1}{k+1} \cdot \lambda_{1a}{}^{2}\right)^{\frac{1}{k-1}} = 0.79$$

Sectional area at the fan inlet at $m_{fan} := 0.04038$

$$F_{в} := \frac{G_{consump} \cdot \sqrt{T^*_{inlet}}}{m_{fan} \cdot P^*_{inlet} \cdot q_{.\lambda 1a}} = \frac{7.6462773673016393 \cdot \sqrt{288}}{0.04038 \cdot 99273 \cdot 0.79048257727893756} = 0.04095 \quad м^{2}$$

Approximate value of the relative diameter of the inlet sleeve $d_{relative} := 0.6$

Bushing (втулки) diameter at compressor inlet

$D_{1c} := 0.27$ м

$$D_{1bush} := \sqrt{D_{1c}{}^{2} - \frac{4 \cdot F_{в}}{\pi}} = 0.15 \quad м$$

2.3.2 Determination of the diametrical dimensions at the outlet of the compressor К-К

Air temperature at the outlet of the high-pressure chamber

$$T^*_{c} := T^*_{inlet} + \frac{k-1}{k} \cdot \frac{L_c}{R} = 604.51 \quad K$$

The degree of air pressure increase in high-pressure chamber

$$\pi_{ch} := \frac{P^*_{c}}{P^*_{inlet}} = \frac{936144}{99273} = 9.43 = 9.43$$

Air velocity in outer of high-pressure chamber $C_{ach} := 140 \ \frac{м}{s}$

Reduced speed and current density

$$\lambda_{ach} := \frac{C_{ach}}{18.3\sqrt{T^*_c}} = \frac{140}{18.3 \cdot \sqrt{604.51044631680952}} = 0.3112 = 0.311$$

$$q_{\lambda ach} := \left[\left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \cdot \lambda_{ach} \cdot \left(1 - \frac{k-1}{k+1} \cdot \lambda_{ach}^{2}\right)^{\frac{1}{k-1}}\right] = 0.471$$

Sectional area at the outlet of the high-pressure chamber

$$F_{ch} := \frac{\left(G_{consump}\right) \cdot \sqrt{T^*_c}}{m_{fan} \cdot P^*_c \cdot q_{\lambda ach}} = 0.011 \quad м^2$$

Bushing diameter of the last stage of the compressor with the combined law of profiling Dmid=const and Dout=const at

$$D_{c.out} := D_{1c} = 0.273 \quad м$$

$$D_{bush.c.out} := \sqrt{D_{c.out}^{2} - \frac{4}{\pi} \cdot F_{ch}} = 0.247 \quad м$$

Height of blades at the outlet of the compressor

$$h_{c.b} := \frac{D_{c.out} - D_{bush.c.out}}{2} = \frac{0.273 - 0.24715047636627041}{2} = 0.01292 = 0.013 \quad м$$

Bushing relative diameter

$$d_{вт.к} := \frac{D_{bush.c.out}}{D_{c.out}} = 0.905$$

2.3.3 Determination of diametrical dimensions at the entrance to the high-pressure chamber Г-Г

$\alpha_1 := 25$

Work high-pressure chamber

$$L_t := L_{st1} + L_{st2} = 324441$$

$$C_1 := \frac{L_{st1}}{u_{mid.t} \cdot \cos\left(\frac{\alpha_1}{57.3}\right)} = \frac{184931}{320 \cdot \cos\left(\frac{25}{57.3}\right)} = 637.6 = 637.6 \quad \frac{м}{s}$$

$$\lambda_1 := \frac{C_1}{18.3\sqrt{T^*_g}} = \frac{637.6}{18.3 \cdot \sqrt{1253}} = 0.9843 = 0.984$$

$$q_{\lambda 1ch} := \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \cdot \lambda_1 \cdot \left(1 - \frac{k-1}{k+1} \cdot \lambda_1{}^2\right)^{\frac{1}{k-1}} = 0.99970271938103543539 = 0.9997$$

Gas flow through the first turbine nozzle at

$\sigma_{nozzle} := 0.98$

$m_г := 0.0396 \quad kg \cdot \frac{K}{J}$

$$G_g := \left(G_{consump}\right) \cdot \left(1 + g_t\right) \cdot \left(1 - g_{cool}\right) = 7.474 \quad \frac{kg}{s}$$

$P^*_{ch} := P^*_c \cdot \sigma_{c.ch} \cdot \sigma_{nozzle} = 936144 \cdot 0.98 \cdot 0.98 = 899072.0 = 899072$

Cross-sectional area of the turbine flow path at the outlet of the turbine nozzle

$$F_{1ch} := \left(\frac{G_g \cdot \sqrt{T^*_g}}{m_г \cdot P^*_{ch} \cdot q_{\lambda 1ch} \cdot \sin\left(\frac{\alpha_1}{57.3}\right)}\right) = 0.018 \quad м^2$$

Average diameter of the turbine flow path at the outlet of the nozzle
(taken from the drawing)

$D_{t.mid} := 0.2741 \quad м$

Height of blades along the trailing edge of the nozzle

$$h_1 := \frac{F_{1ch}}{\pi \cdot D_{t.mid}} = \frac{0.017590565225400936}{\pi \cdot 0.2741} = 0.02043 = 0.02 \quad м$$

Turbine impeller diameter

$$D_{HPT} := D_{t.mid} + h_1 = 0.2741 + 0.02043 = 0.2945 = 0.295 \quad м$$

Bushing diameter

$$D_{bush.htp} := \sqrt{D_{HPT}{}^2 - \frac{4}{\pi} \cdot F_{1ch}} = 0.254 \quad м$$

Determine the axial gas velocity at the inlet to the impeller

$$C_{1a} := C_1 \cdot \sin\left(\frac{\alpha_1}{57.3}\right) = 269.443 \quad \frac{м}{с}$$

2.3.4 Determination of diametrical dimensions at the outlet of the high-pressure turbine Тв-Тв

Gas temperature and pressure at the outlet of the high-pressure turbine

$$\eta^*_{HPT} := 0.89$$

$$T^*_{HPT} := T^*_g - \frac{L_t}{\frac{k_g}{k_g - 1} \cdot R_g} = 1253 - \frac{324441}{\frac{1.33}{1.33 - 1} \cdot 288} K = 973.5 = 973.5 \qquad T$$

$$P^*_{HPT} := P^*_{ch} \cdot \left(1 - \frac{T^*_g - T^*_{HPT}}{T^*_g \cdot \eta^*_{HPT}}\right)^{\frac{k_g}{k_g - 1}} = 281042.661 \qquad Pa$$

Reduced speed and current density

$$C_{HPT.out} := 250 \quad \frac{м}{s}$$

$$\lambda_{2a} := \frac{C_{HPT.out}}{\sqrt{2 \cdot R_g \cdot T^*_{HPT} \cdot \frac{k_g}{k_g + 1}}} = 0.442$$

$$q_{\lambda 2} := \left(\frac{k_g + 1}{2}\right)^{\frac{1}{k_g - 1}} \cdot \lambda_{2a} \cdot \left(1 - \frac{k_g - 1}{k_g + 1} \cdot \lambda_{2a}^{\ 2}\right)^{\frac{1}{k_g - 1}} = 0.645$$

Gas consumption at the outlet of the turbine

$$g_{cool2} := 0.04$$

$$G_g := \left[\left(G_{consump}\right) \cdot \left(1 + g_t\right) \cdot \left(1 - g_{cool2}\right)\right] = 7.474 \qquad \frac{kg}{s}$$

The cross-sectional area of the turbine flow path at the outlet from HPT

$$F_{HPT} := \frac{G_g \cdot \sqrt{T^*_{HPT}}}{m_г \cdot P^*_{HPT} \cdot q_{\lambda 2}} = 0.033 \qquad м^2$$

Find the height of the blade at the outlet of the high-pressure turbine

$$h_2 := \frac{F_{HPT}}{\pi \cdot D_{t.mid}} = 0.038$$

Find the diameter at the outlet of the high-pressure turbine

$$D_{bush.out.HPT} := D_{t.mid} - h_2 = 0.236 \quad м$$

$$D_{out.HPT} := \sqrt{D_{bush.out.HPT}^{2} + \frac{4}{\pi} \cdot F_{HPT}} = 0.312 \quad м$$

Height of blades at the outlet of the high-pressure turbine

2.3.5 Determination of the number of stages of the high pressure compressor

Peripheral speeds at the periphery and at the first stage bushing and at the bushing

$$u_{1c} := u_{mid.t} \cdot \frac{D_{1c}}{D_{t.mid}} = 320 \cdot \frac{0.273}{0.2741} = 318.7 = 318.7 \quad \frac{м}{s}$$

$$u_{1bush} := u_{mid.t} \cdot \frac{D_{1bush}}{D_{t.mid}} = 320 \cdot \frac{0.14963235159247848}{0.2741} = 174.7 = 174.7 \quad \frac{м}{s}$$

$$u_{z.bush} := u_{mid.t} \cdot \frac{D_{bush.c.out}}{D_{t.mid}} = 320 \cdot \frac{0.24715047636627041}{0.2741} = 288.5 = 288.5 \quad \frac{м}{s}$$

Closeness coefficients of the first and last stages

$$b_{tbush1} := 1.4 \qquad b_{tbush2} := 1.8$$

Swirling in the impeller in the first and last stages

$$\Delta W_{u1.bush} := C_{1a} \cdot \frac{1.55}{1 + \frac{1.5}{b_{tbush1}}} = 180 \cdot \frac{1.55}{1 + \frac{1.5}{1.4}} = 134.7 = 134.7 \quad \frac{м}{s}$$

$$\Delta W_{uz.bush} := C_{ach} \cdot \frac{1.55}{1 + \frac{1.5}{b_{tbush2}}} = 140 \cdot \frac{1.55}{1 + \frac{1.5}{1.8}} = 118.4 = 118.4 \quad \frac{м}{s}$$

Work of the blades in the first and last steps

$$L_{c.st1} := u_{1bush} \cdot \Delta W_{u1.bush} = 174.7 \cdot 134.7 = 23532.0 = 23532 \quad \frac{J}{kg}$$

$$L_{c.st.z} := u_{z.bush} \quad \frac{J}{kg}$$

Average operation of high pressure compressor stages

$$L_{mid} := \frac{L_{c.st1} + L_{c.st.z}}{2} = \frac{23532 + 288.5}{2} = 11910.0 = 11910$$

$$z_k := \frac{L_c}{L_{mid}} = \frac{312395.81051469105}{11910} = 26.23 = 26.23$$

Take the number of steps: $z_{HPC} := 12$ the height of the last steps is small, the work on them is reduced

Checking the condition of compliance with the power balance

$$N_c := G_{consump} \cdot L_c = 2388665.016 \quad kVt$$

$$N_{HPT} := G_g \cdot L_t = 7.4744963767266244 \cdot 324441 = 2.425e6 = 2425000 \quad kVt$$

Checking rotation frequency

$$n_c := \frac{60 \cdot u_{1c}}{\pi \cdot D_{1c}} = \frac{60 \cdot 318.7}{\pi \cdot 0.273} = 22295.0 \quad rpm$$

$$n_{HPT} := \frac{60 \cdot u_{mid.t}}{\pi \cdot D_{t.mid}} = \frac{60 \cdot 320}{\pi \cdot 0.2741} = 22296.0 \quad rpm \qquad u_{mid.t} = 320$$

2.3.6 Determination of the number of stages and distribution of work among the stages of a free turbine

$T^*_{HPT} = 973.5$ К No need in cooling (T less than 1200K)

$$G_{air1} := G_{consump} = 7.646 \quad kg \cdot s^{-1}$$

$$G_{g.LPT} := G_{air1} \cdot \left(1 + g_t\right) = 7.786 \quad kg \cdot s^{-1}$$

Free turbine operation

$$L_{free.t} = 213205 \quad \frac{J}{kg}$$

Average diameter on the enter to the low pressure turbine

taken from drawing

$D_{LPT.mid} := 0.28$ м

$$u_{LPT.mid} := u_{1c} \cdot \frac{D_{LPT.mid}}{D_{1c}} = 318.7 \cdot \frac{0.28}{0.273} = 326.9 = 326.9 \quad \frac{м}{s}$$

Low pressure turbine stages

$z_{LPT} := 2$

Loading coefficient $\eta_{з.тнд} := 0.89$

$$Y_т := u_{LPT.mid} \cdot \sqrt{\frac{z_{LPT} \cdot \eta_{з.тнд}}{2 \cdot L_{free.t}}} = 326.9 \cdot \sqrt{\frac{2 \cdot 0.89}{2 \cdot 213205}} = 0.6679 = 0.668$$

$$L_{LPT1} := \frac{57}{100} \cdot L_{free.t} = 121526.85 \quad \frac{J}{kg} \qquad L_{LPT2} := \frac{43}{100} \cdot L_{free.t} = 91678.15 \quad \frac{J}{kg}$$

$$L_{LPT1} + L_{LPT2} = 213205 \quad \frac{J}{kg} \qquad L_{free.t} = 213205 \quad \frac{J}{kg}$$

2.3.7 Determination of diametrical dimensions at the entrance to a free turbine

Gas outflow rate from the first nozzle free turbine

$$C_{in.LPT} := \frac{L_{LPT1}}{u_{LPT.mid} \cdot 0.9063} = \frac{121526.84999999999}{326.9 \cdot 0.9063} = 410.2 = 410.2 \quad \frac{м}{s}$$

Reduced speed (приведённая)

$$\lambda_{in.LPT} := \frac{C_{in.LPT}}{\sqrt{2 \cdot R_g \cdot T^*_{HPT} \cdot \frac{k_g}{k_g + 1}}} = \frac{410.2}{\sqrt{2 \cdot 288 \cdot 973.5 \cdot \frac{1.33}{1.33 + 1}}} = 0.7251 = 0.725$$

Current density

$$q_{\lambda LPT} := \left(\frac{k_g + 1}{2}\right)^{\frac{1}{k_g-1}} \cdot \lambda_{in.LPT} \cdot \left(1 - \frac{k_g - 1}{k_g + 1} \cdot \lambda_{in.LPT}^{\,2}\right)^{\frac{1}{k_g-1}} = 0.911$$

The recovery factors of the total pressure in the transition housing of the high-pressure turbine and in the low-pressure turbine and in the nozzle

$$\sigma_{nozzle.LPT} := 0.98$$

Sectional area at the outlet of the nozzle apparatus of a low-pressure turbine

$$F_{1nozzle.LPT} := \frac{G_{g.LPT} \cdot \sqrt{T^*_{HPT}}}{m_г \cdot P^*_{HPT} \cdot \sigma_{nozzle.LPT} \cdot q_{\lambda LPT} \cdot \sin\left(\frac{\alpha_1}{57.3}\right)} = 0.058 \quad м^2$$

Low pressure turbine blade height

$$h_{b.LPT} := \frac{F_{1nozzle.LPT}}{\pi \cdot D_{LPT.mid}} = \frac{0.057852421777172577}{\pi \cdot 0.28} = 0.06577 = 0.066 \quad м$$

$$D_{bush.LPT} := D_{LPT.mid} - h_{b.LPT} = 0.214 \quad м$$

Outside diameter at the inlet to the low pressure turbine

$$D_{LPT} := D_{LPT.mid} + h_{b.LPT} = 0.28 + 0.06577 = 0.3458 = 0.346 \quad м$$

2.3.8 Determination of diametrical dimensions at the outlet of a low-pressure turbine T-T

Gas parameters at the outlet of a low-pressure turbine

$$\sigma_{LTP} := 0.975$$

$$T^*_{LPT} := T^*_{HPT} - \frac{L_{free.t}}{\frac{k_g}{k_g - 1} \cdot R_g} = 973.5 - \frac{213205}{\frac{1.33}{1.33 - 1} \cdot 288} = 789.8 = 789.8 \quad К$$

$$P_{з.тнд} := P^*_{HPT} \cdot \sigma_{LTP} \cdot \left(1 - \frac{T^*_{HPT} - T^*_{LPT}}{T^*_{HPT} \cdot \eta_{з.тнд}}\right)^{\frac{k_g}{k_g-1}} = 104880.522 \quad Pa$$

We set the value of the axial component of the gas velocity at the outlet of the low-pressure turbine

$$C_{1LPT} := 306 \quad \frac{м}{s}$$

Reduced speed

$$\lambda_{out.LPT} := \frac{C_{1LPT}}{\sqrt{2 \cdot R_g \cdot T^*_{LPT} \cdot \frac{k_g}{k_g + 1}}} = 0.6$$

Current density

$$q_{\lambda out.LPT} := \left[\left(\frac{k_g + 1}{2} \right)^{\frac{1}{k_g - 1}} \cdot \lambda_{out.LPT} \cdot \left[1 - \frac{k_g - 1}{k_g + 1} \cdot \left(\lambda_{out.LPT} \right)^2 \right]^{\frac{1}{k_g - 1}} \right] = 0.814$$

Sectional area at the outlet of the low pressure turbine

$$F_{LPT.out} := \frac{G_{g.LPT} \cdot \sqrt{T^*_{LPT}}}{m_г \cdot P_{з.тнд} \cdot q_{\lambda out.LPT}} = 0.065 \quad м^2$$

$$D_{mid.out.LPT} := 0.2845$$

Blade height at the outlet of the low pressure turbine

$$h_{b.out.LPT} := \frac{F_{LPT.out}}{\pi \cdot D_{mid.out.LPT}} = \frac{0.064740361589902609}{\pi \cdot 0.2845} = 0.07243 = 0.072 \quad м$$

Diameter value at the outlet of the low pressure turbine

$$D_{out.LPT} := D_{mid.out.LPT} + h_{b.out.LPT} = 0.357 \quad м$$

Low pressure turbine bushing diameter

$$D_{bush.out.LPT} := D_{mid.out.LPT} - h_{b.out.LPT} = 0.212 \quad м$$

Low pressure turbine rotate frequency

$$\frac{60 \cdot u_{LPT.mid}}{\pi \cdot D_{LPT.mid}} = \frac{60 \cdot 326.9}{\pi \cdot 0.28} = 22297.0 \qquad n_{LPT} := 5720 \ min^{-1}$$

2.3.9 Determination of diametrical sections at the exit from the nozzle C-C

Reduced gas velocity at the nozzle exit

$$\lambda_{nozzle} := \frac{C_{out}}{18.15 \cdot \sqrt{T^*_{LPT}}} = \frac{203.90035565283131}{18.15 \cdot \sqrt{789.8}} = 0.3997 = 0.4$$

Current density

$$q_{\lambda nozzle} := \left(\frac{k_g + 1}{2}\right)^{\frac{1}{k_g - 1}} \cdot \lambda_{nozzle} \cdot \left(1 - \frac{k_g - 1}{k_g + 1} \cdot \lambda_{nozzle}{}^2\right)^{\frac{1}{k_g - 1}} = 0.592$$

Nozzle area

$$F_{nozzle} := \frac{G_g \cdot \sqrt{T^*_{LPT}}}{m_г \cdot P_{з.тнд} \cdot q_{\lambda nozzle}} = 0.085 \quad м^2$$

Nozzle diameter

$$D_{nozzle} := \sqrt{\frac{4 \cdot F_{nozzle}}{\pi}} = \sqrt{\frac{4 \cdot 0.085378558479152239}{\pi}} = 0.3297 = 0.33 \quad м$$

2.3.10 Clarify of engine parameters

Checking the power balance in the low pressure turbine

$$N_{LPT} := G_{g.LPT} \cdot L_{free.t} = 1660000 \qquad kVt$$

2.3.11 Throttle characteristic

Formulas and calculations are written in table 2.2

Parameter and calculation formula	Throttle characteristic					
n_{o_i}	0.8	0.85	0.9	0.95	1.0	1.05
T^*_{air}	288	288	288	288	288	288
$P_н$	101325	101325	101325	101325	101325	101325
$n_{зв_i} := n_{o_i} \cdot \sqrt{\frac{288}{T^*_{air}}}$	0.8	0.85	0.9	0.95	1.0	1.05
$\pi^*_c := \left(n_{зв}^{\langle 0 \rangle}\right)^a$ $a := \pi^*_{c.c}{}^{0.2} = 1.566$	0.705	0.775	0.848	0.923	1	1.079
$\pi^*_{c.no} := \pi^*_{c.c} \cdot \pi^*_c$	6.648	7.311	7.995	8.702	9.43	10.179
$\eta^*_{c1} :=$ $z \leftarrow 0$ for $i \in 0,1..5$ $X_z \leftarrow \left(n_{зв_z}\right)^{b_z}$ $z \leftarrow z + 1$ X $b := \pi^*_{c.c}{}^{0.1} \cdot \left[n_{зв}^{\langle 0 \rangle} - \left(n_{зв}^{\langle 0 \rangle}\right)^2\right]$	0.956	0.974	0.988	0.997	1	0.997
$\eta^*_{c.no} := \eta^*_{c1} \cdot \eta^*_{c.c}$	0.801	0.816	0.828	0.835	0.837	0.835
$L_{c1} :=$ $z \leftarrow 0$ for $i \in 0,1..5$ $X_z \leftarrow \frac{k \cdot R \cdot T^*_{air}}{k-1} \cdot \left[\left(\pi^*_{c.no_z}\right)^{\frac{(k-1)}{k}} - 1\right] \cdot \frac{1}{\eta^*_{c.no_z}}$ $z \leftarrow z + 1$ X	260796.739	272871.952	285217.755	298251.358	312395.811	328093.977
$T^*_c := T^*_{air} + \frac{L_{c1}}{\left[\frac{k \cdot R}{(k-1)}\right]}$	552.22	564.46	576.97	590.18	604.51	620.41

$P^*_g := P_н \cdot \pi^*_{c.no} \cdot \sigma_{c.c} \cdot \sigma_{in.c}$	646964.915	711413.901	778047.262	846811.484	917657.158	990538.474
$T^*_g := \frac{T^*_{g.c} \cdot L_{c1}}{L_{c.c}}$	1046.0	1094.4	1143.9	1196.2	1253	1315.9
$c_c := 878 + 0.208 \cdot \left(T^*_g + 0.48 \cdot T^*_c\right)$	1150.7	1162.0	1173.5	1185.7	1198.9	1213.6
$g_{fuel} := \left\lvert \begin{array}{l} z \leftarrow 0 \\ \text{for } \; i \in 0,1..5 \\ \quad \left\lvert \begin{array}{l} X_z \leftarrow \left[c_{c_z} \cdot \frac{\left(T^*_{g_z} - T^*_{c_z}\right)}{\left(H_u \cdot \eta_{г.р}\right)} \right] \\ z \leftarrow z + 1 \end{array} \right. \\ X \end{array} \right.$	0.013	0.014	0.016	0.017	0.018	0.02
$L_{t.k} := \frac{L_{c1}}{\left[\left(1 + g_{fuel}\right) \cdot \left(1 - g_{cool}\right) \cdot \eta_м\right]}$	272167	284454	296983	310173	324442	340222
$T^*_{rc} := T^*_g - \frac{L_{t.k} \cdot \left(k_g - 1\right)}{\left(k_g \cdot R_g\right)}$	811.55	849.40	888.13	929.04	973.48	1022.8
$P^*_{rc} := \left\lvert \begin{array}{l} z \leftarrow 0 \\ \text{for } \; i \in 0,1..5 \\ \quad \left\lvert \begin{array}{l} X_z \leftarrow P^*_{g_z} \cdot \left(1 - \frac{T^*_{g_z} - T^*_{rc_z}}{T^*_{g_z} \cdot \eta^*_{т.к.р}}\right)^{\frac{k_g}{k_g - 1}} \\ z \leftarrow z + 1 \end{array} \right. \\ X \end{array} \right.$	200900.889	221244.971	242343.454	264201.017	286829.9	310251.383
$L_{n.t} := \left\lvert \begin{array}{l} z \leftarrow 0 \\ \text{for } \; i \in 0,1..5 \\ \quad \left\lvert \begin{array}{l} X_z \leftarrow \frac{\left(k_g \cdot R_g \cdot T^*_{rc_z}\right)}{\left(k_g - 1\right)} \cdot \left[1 - \left(\frac{P^*_{т.р}}{P^*_{rc_z}}\right)^{\frac{k_g - 1}{k_g}}\right] \cdot \eta_т \\ z \leftarrow z + 1 \end{array} \right. \\ X \end{array} \right.$	115347.083	138856.023	162674.978	187135.346	212654.971	239739.067

$N_{c.п} :=$ $z \leftarrow 0$ $\text{for } i \in 0,1..5$ $\quad X_z \leftarrow L_{n.t_z} \cdot \eta_e \cdot \left(1 + g_{fuel_z}\right)$ $\quad z \leftarrow z + 1$ X	33053.109	39833.621	46720.111	53811.292	61232.674	69137.491
$G_c :=$ $z \leftarrow 0$ $\text{for } i \in 0,1..5$ $\quad X_z \leftarrow G_{c.c} \cdot \frac{P^*_{g_z}}{P^*_{г.p}} \cdot \sqrt{\frac{T^*_{g.c}}{T^*_{g_z}}}$ $\quad z \leftarrow z + 1$ X	5.902	6.344	6.787	7.223	7.648	8.056
$C_{n.no} := 3600 \cdot \frac{g_{fuel}}{N_{c.п}}$ $\quad C_{n.no} \cdot 10^3$	0.158	0.171	0.185	0.2	0.216	0.235
$N_{n.no} := N_{c.п} \cdot G_c$	1792811.6	1927293.7	2061686.8	2194322.8	2323447.5	2447243.7
$G_t := 3600 \cdot G_1 \cdot \left(1 - g_{cool.c} - g_{orp}\right) \cdot g_t$	372.5	400.4	428.3	455.9 4	482.7	508.5

Table 2.2

2.3.14 Converted calculations into the graph

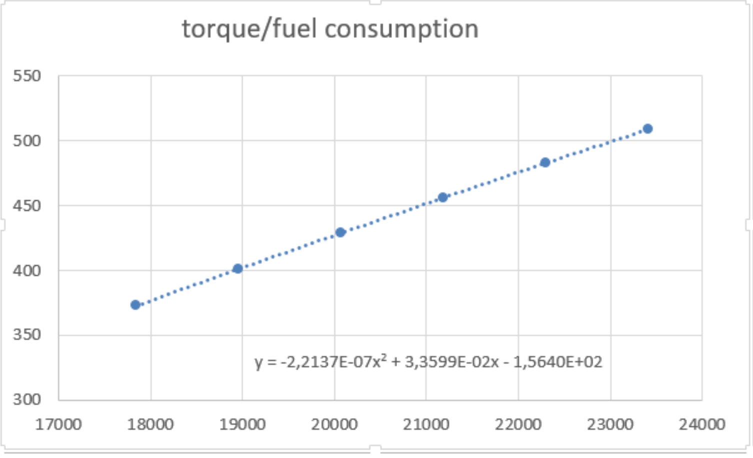


Fig. 2.2 Torque to fuel consumption

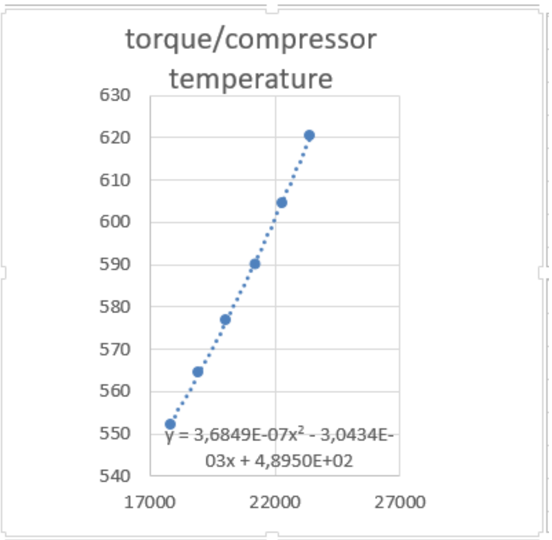


Fig. 2.3 Torque to compressor temperature

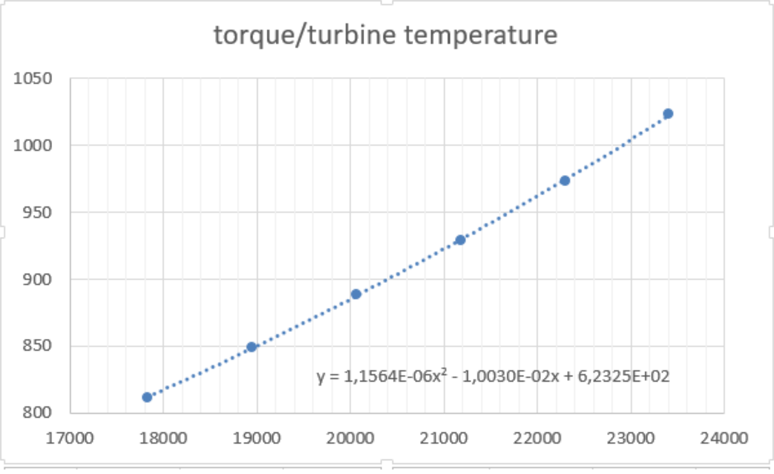


Fig. 2.4 Torque to turbine temperature

Formulas for reference models

Torque to fuel consumption

$$y = -2{,}2137\cdot10^{-7}\cdot n_r^2 + 3{,}3599\cdot10^{-2}\cdot n_r - 1{,}5640\cdot10^2 \qquad (2.1)$$

Torque to compressor temperature

$$y = 3{,}6849\cdot10^{-7}\cdot n_r^2 - 3{,}0434\cdot10^{-3}\cdot n_r + 4{,}8950\cdot10^2 \qquad (2.2)$$

Torque to turbine temperature

$$y = 1{,}1564\cdot10^{-6}\cdot n_r^2 - 1{,}0030\cdot10^{-2}\cdot n_r + 6{,}2325\cdot10^2 \qquad (2.2)$$

Conclusions for part 2

We calculate thermo and gas-dynamic parameters and dimensions in engine on different sections:

engine section B-B;

behind the compressor - section K-K;

combustion chamber -section Г-Г;

behind the high-pressure turbine - section Тв-Тв;

Calculated gas velocity and static parameters. Determined the number of stages of the high-pressure compressor. Determinated the number of stages and distribution of work among the stages of a free turbine.

Calculated throttle characteristics and converted calculations into the graph.

PART 3

METHOD OF DIAGNOSING THE FLOW PART OF A GAS TURBINE ENGINE BY THERMOGAS DYNAMIC PARAMETERS

3.1 General description of the diagnostic method

Diagnosis of GTD using thermogasodynamic parameters (parametric diagnostic method) as carriers of diagnostic information is based on special mathematical processing and analysis of parameter values measured on a running engine. Thermogasodynamic parameters include air and gas pressure and temperature in different cross sections of the engine, fuel consumption, rotor speed, etc. The essence of the parametric diagnostic method is that the deviations of the measured parameter values from their base values are determined. According to the magnitude of the deviations, a conclusion is made about the correct operation of the engine and its serviceability. With a sufficient range of measured parameters, it is possible to perform diagnostics in order to search for a fault (defect), ie to indicate the component of the engine that has a defect. Values of parameters of the serviceable engine received at carrying out factory delivery, tests (form values) or values of parameters of the engine in the initial period of its operation (the first 10 .... 20 flights) are usually used as base.

The method of diagnostics on thermogasodynamic parameters can be applied to detection only of those malfunctions (defects) which lead to change, parameters of working process of the engine. These include various deviations in the geometry of the elements of the flowing part of the engine due to erosion and pollution, burnout of the blades of turbine nozzles, damage (deformation), breakage, melting of compressor blades and turbines, destruction of sealing layers in the inner air. , and also malfunctions of control systems of the engine connected with shrinkage of springs centrifugal Sensors, incorrect adjustment or malfunctions of control systems, reverse of draft, etc. Faults (defects), not Leading to change of parameters of working process GTD - cracks in the structural elements, malfunctions of the rotor supports in the initial stage, etc., cannot be detected by the described method.

The peculiarity of the application of the method of diagnosis by thermogasodynamic parameters is that the engine parameters are interrelated by relations arising from the well-consistent with the practice of GTD theory. There is a possibility of rather strict mathematical description of the working process of the engine, creation of the diagnostic mathematical model reflecting influence of malfunctions (defects) of various knots of a flowing part on, thermogasodynamic parameters. basic) values to assess the value of the imputation of the characteristics of the units - the efficiency of compressors and their performance, efficiency and capacity of turbines, etc., as well as the characteristics of the engine as a whole - thrust, power, specific fuel consumption. - Parameters describing the functional properties of engine components, their efficiency, productivity, loss coefficients, in the theory of gas turbine engines are called primary in contrast to the secondary parameters that depend on them - pressures, temperatures, air and gas consumption, rotor speeds.

All secondary parameters can in principle be measured, although usually only a part of them is measured. g theories of technical diagnostics The values that characterize the ability of the diagnostic object to perform its functional properties are called state parameters. Values that are functionally or probably related to them are signs of the state. The attribute (parameter) of the object, used in the prescribed manner to determine the technical condition, is called diagnostic. In the case of parametric diagnostics, the primary parameters of the GTD are, therefore, the parameters of the state, the secondary - the signs of the state, and the measured parameters - diagnostic. Registration of measurement results can be carried out manually or automatically by means of special devices. The latter are most often used magnetic recorders such as Automatic registration has a number of advantages :, simultaneous recording of many parameters, registration in transient modes, a large amount of information due to its continuous recording. Currently, both types of registration are used, but for some engines, including НК-8-2У, manual recording of engine parameters by the crew in flight and ground composition when testing engines is also used. For diagnostics at manual registration of parameters indications of regular devices which were traditionally used for control of engines, control of their operability, the decision of navigation problems are used.

Regardless of the type of GTD, the number and nomenclature of measured parameters, the method of their registration, the processing of measurement results for diagnostic purposes contains a number of mandatory computational operations. These are:

bringing the measured parameters to standard atmospheric conditions (ACS), bringing to a given mode of operation and determining the deviations of the thus found values of their basic values in this mode, comparing deviations with their limits and determining the type of technical condition of the engine (working, faulty), analysis of the obtained results in order to identify the fault location In the case of multiple measurements in the above sequence of calculations are added elements of statistical processing: , exponential, etc.). As a result of such processing the accuracy of estimation of deviations of parameters from base increases and the tendency of their changes is revealed. In the present work, the entire diagnostic procedure is performed except for statistical processing, as the measurement is one-time. Measurement of parameters, their reduction to ACS and the set mode of operation of the engine, definition of deviations from base values, the analysis for the purpose of definition of a technical condition of the engine have to be carried out.

3.1.1 Used sensors and their parameters

The figures - sensors that are selected for installation on engine.

Model 522M37A

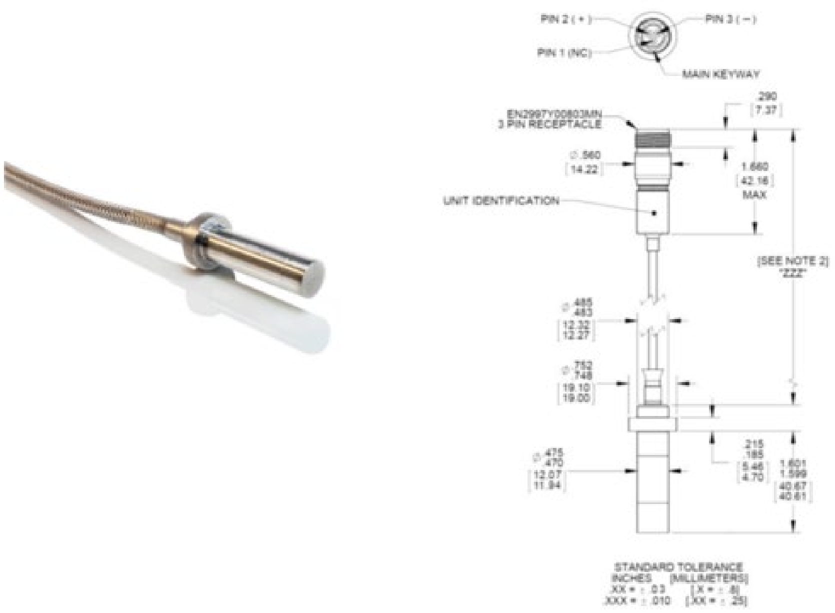


Fig. 3.1 Pressure sensor

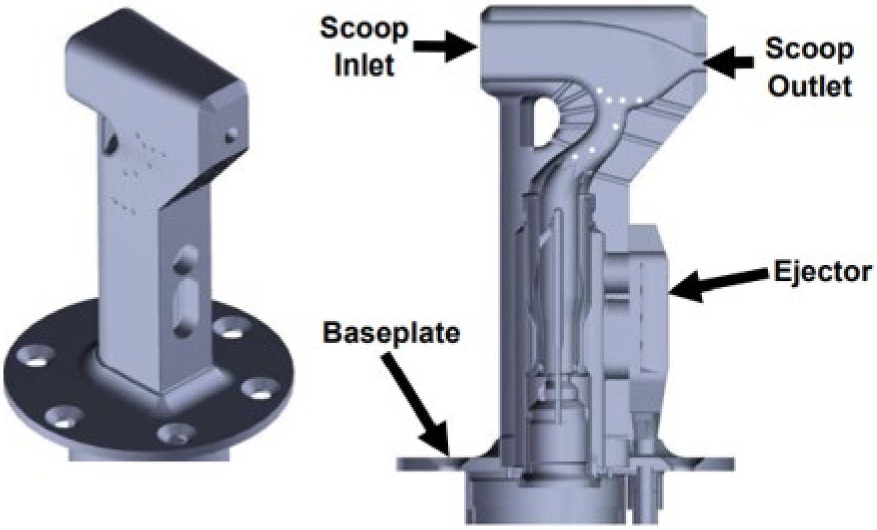


Fig. 3.2 Inlet temperature sensor

Fig. 3.3 Rotation frequency sensor

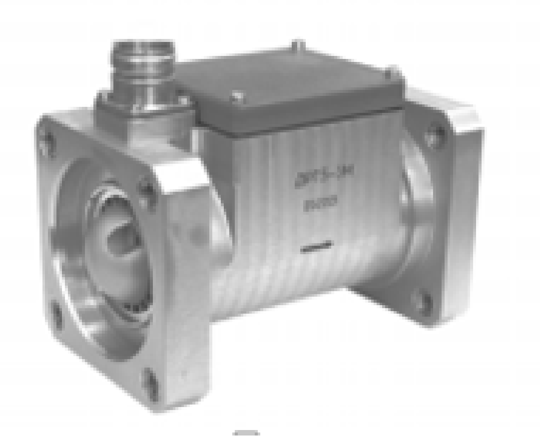


Fig. 3.4 Fuel consumption sensor

Fig. 3.5 After compressor temperature sensor

Fig. 3.6 Turbine temperature sensor

Options measurements	The values on takeoff	Brand sensor	measurement range which the fits to takeoff	Measurement error in%	Measurement error in units	manufacturer
Total engine inlet pressure	101300 Pa	522M37A	140000 Па		±700	MEGGIT
Total engine inlet temperature	15 °c	0105TAT	-70°C to +250°C		±0.1°C	Collins Aerospace
Rotor speed in a turbocharger	22300 rpm		Turbine / rotor speeds up to 60,000rpm	±0.025%	±30rpm	AuxitrolWeston
Fuel consumption per hour	620 kg/h	ДРТ5-3М	300…750 – kg/h	+/- 1%	±7.5 kg/h	«Прибор»
Compressor total temperature	331.35°c		from -54°C to +1200°C	Accuracy: 0.4% at 1000°C	±4°C	MEGGIT
Total temperature between turbines	700°c		Temperature range -55°c to 1260 °c		±1°C	HarcoSemko

3.2 Table

3.1.2 Reduction of the parameter to standard atmospheric conditions

Deciding on the type of technical condition of the engine, as noted above, is carried out by comparing the values of certain parameters with the norms for their tolerances.

Reduced value of the rotor speed Reduced value of the total temperature in any section of the flow path:

$$n_{пр} := n_{компрессора} \cdot \sqrt{\frac{288}{T^*_{H}}}$$

$$T^*_{пр.т} := T_{турбина} \cdot \frac{288}{T^*_{H}}$$

$$T^*_{пр.к} := T_{компрессором} \cdot \frac{288}{T^*_{H}}$$

Fuel consumption:

$$G_{П.зв} := G_{расход} \cdot \frac{101325}{P^*_{H}} \cdot \sqrt{\frac{288}{T^*_{H}}}$$

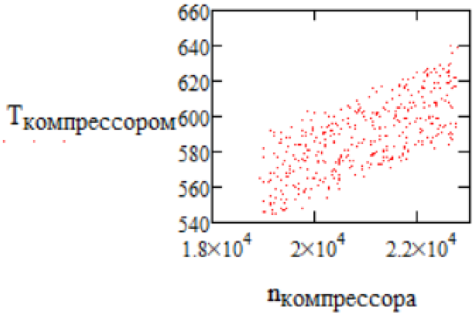
Reference values:

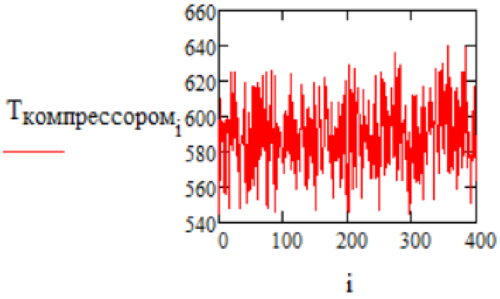
$$T_{к.эталон} := 3.6849 \cdot 10^{-7} \cdot n_{пр}^{2} - 0.0030434 \cdot n_{пр} + 489.5$$

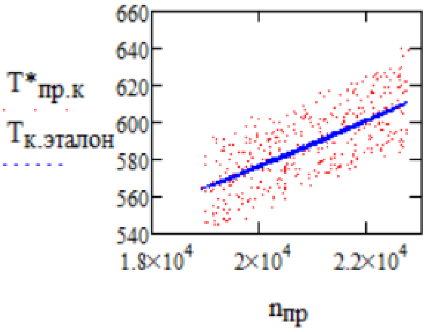
$$T_{т.эталон} := 1.1564 \cdot 10^{-6} \cdot n_{пр}^{2} - 0.01003 \cdot n_{пр} + 623.25$$

$$G_{П.эталон} := -2.2137 \cdot 10^{-7} \cdot n_{пр}^{2} + 0.033599 \cdot n_{пр} - 156.4$$

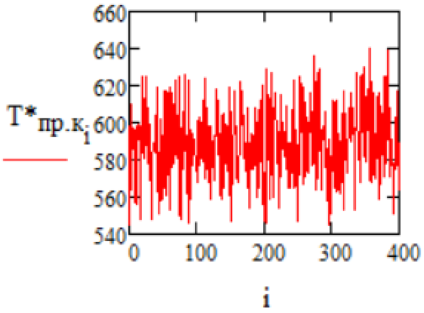
compressor





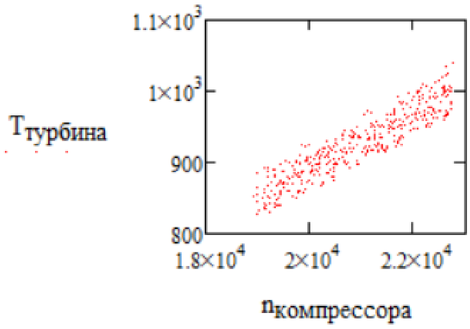


T*пр.к
Tк.эталон
660
640
620
600
580
560
540
1.8×10^4
2×10^4
2.2×10^4
nпр

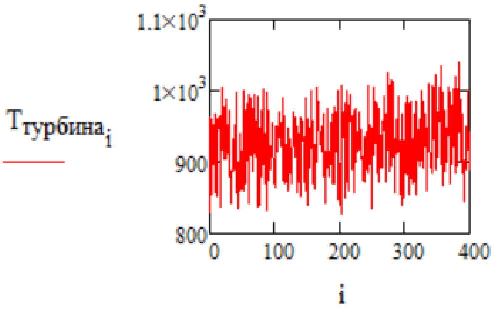


T*пр.к_i
660
640
620
600
580
560
540
0
100
200
300
400
i

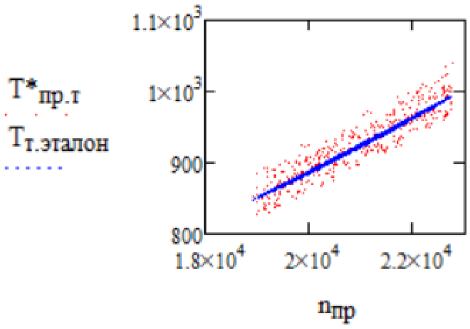
turbine



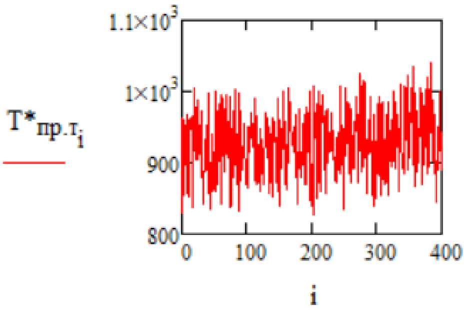
Tтурбина
1.1×10^3
1×10^3
900
800
1.8×10^4
2×10^4
2.2×10^4
nкомпрессора



Tтурбина_i
1.1×10^3
1×10^3
900
800
0
100
200
300
400
i

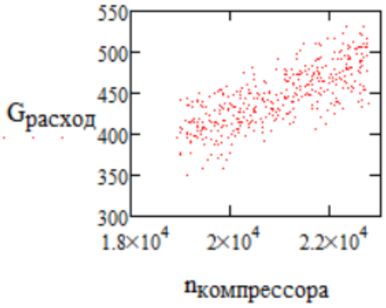


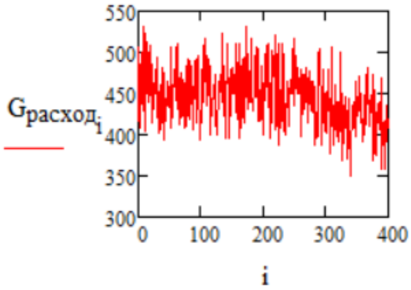
T*пр.т
Tт.эталон
1.1×10^3
1×10^3
900
800
1.8×10^4
2×10^4
2.2×10^4
nпр

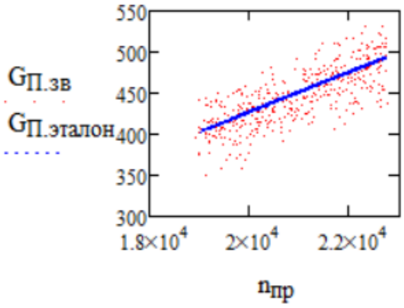


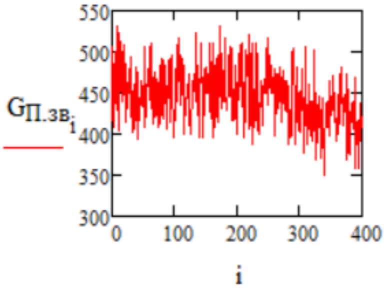
T*пр.т_i
1.1×10^3
1×10^3
900
800
0
100
200
300
400
i

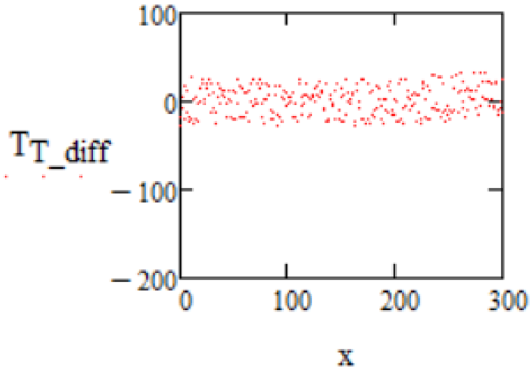
fuel consumption



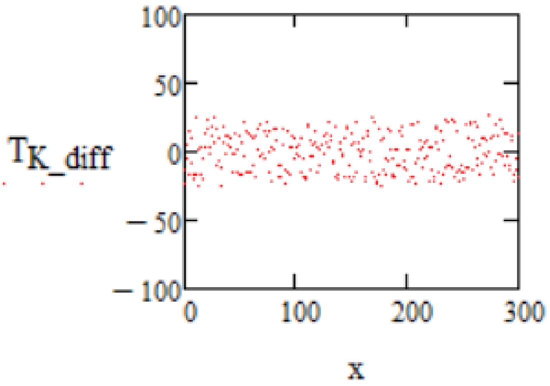




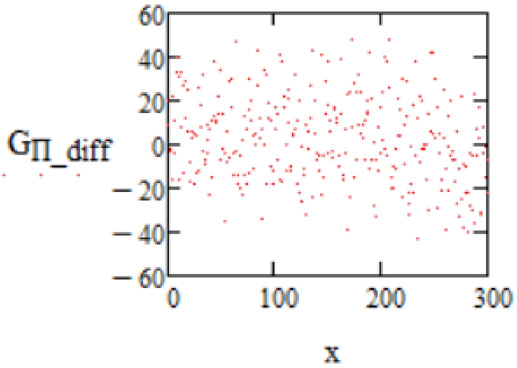




$T_{K\_diff} := T^*_{пр.к} - T_{к.эталон}$



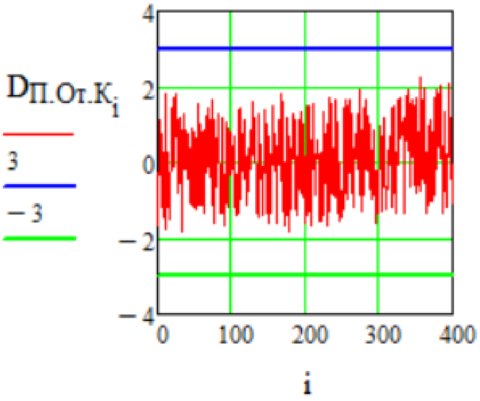
$T_{T\_diff} := T^*_{пр.т} - T_{т.эталон}$



$G_{П\_diff} := G_{П.зв} - G_{П.эталон}$

Standardization of attribute of technical condition

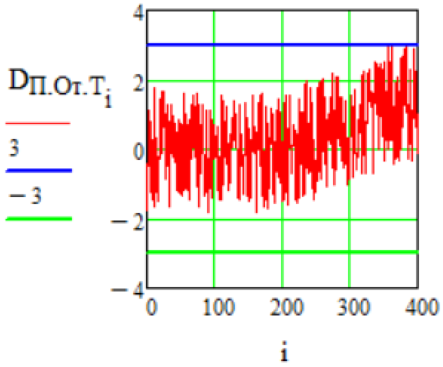
For compressor:



$$D_{П.От.К} := \frac{T_{К\_diff}}{D_{П.норм.К}}$$

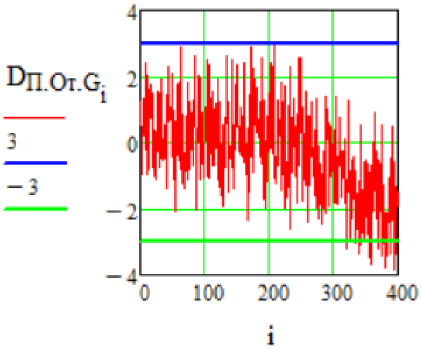
For turbine

$$D_{П.От.T} := \frac{T_{T\_diff}}{D_{П.норм.T}}$$



For fuel consumption

$$D_{П.От.G} := \frac{G_{П\_diff}}{D_{П.норм.G}}$$

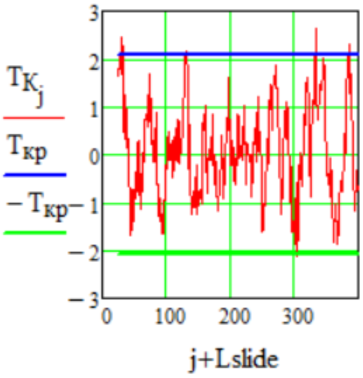


3.1.3 Checking signs of a technical condition for a trend

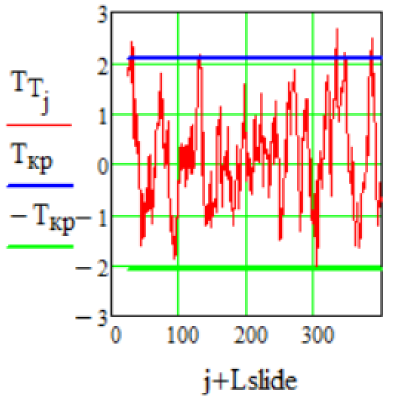
We take L points from the previous graph and use them to calculate the correlation coefficient and the observed value of the Student's parameter. Move the line by one point and repeat the calculation until we have L points to the end of the data.

Length of the sliding strip

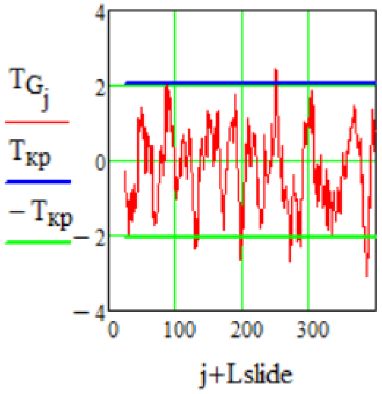
Lslide := 25



For compressor



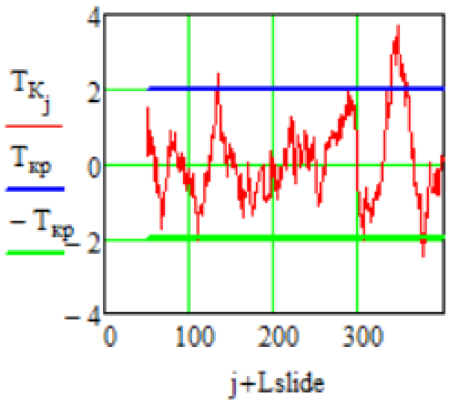
For turbine



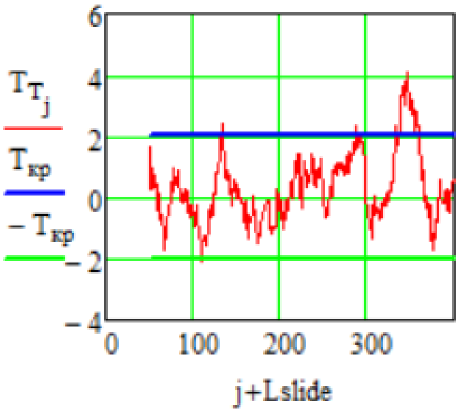
For fuel consumption

Length of the sliding strip

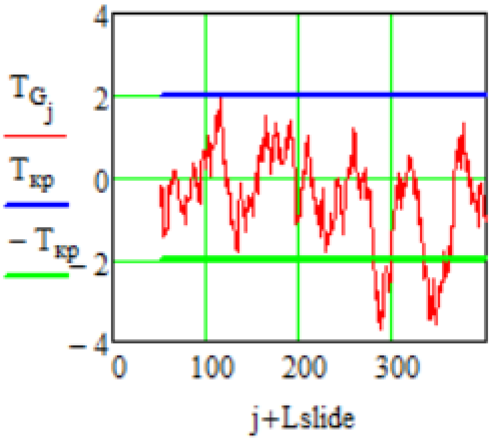
Lslide := 50



For compressor



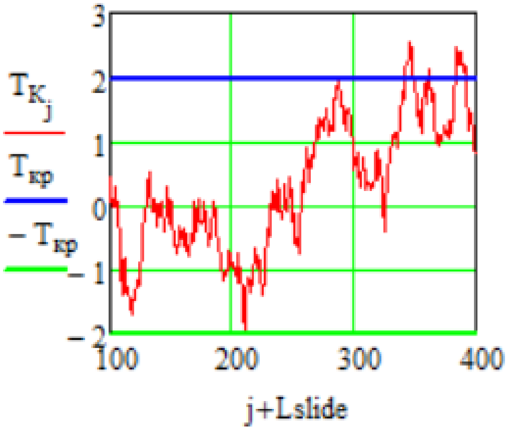
For turbine



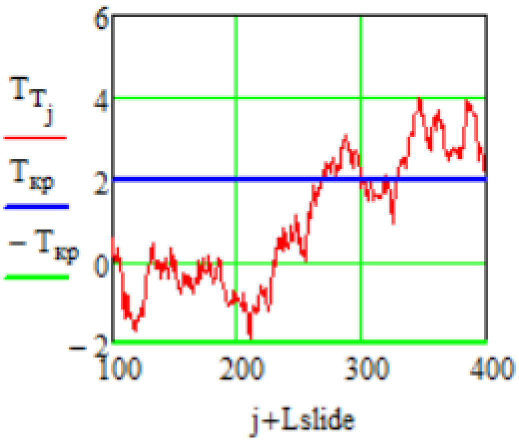
For fuel consumption

Length of the sliding strip

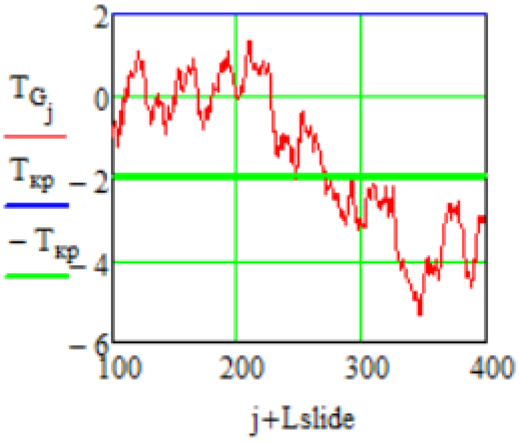
Lslide := 100



For compressor



For turbine



For fuel consumption

Conclusions for part 3

As a conclusion to the third part, it is worth mentioning what was modeling the process of degradation of the engine flow path and its detection by numerical experiment and processing of its results, detection of dependence, including sensors deviations and reduction of the parameter to standard atmospheric conditions.

PART 4

ENVIRONMENTAL PROTECTION

4.1 Aviation industry pollution

Worldwide, flights produced 915 million tons of CO2 in 2019. Globally, humans produced over 43 billion tons of CO2. In 2019, 4.5 billion passengers were carried by the world's airlines. Nearly 88 million jobs were supported worldwide in aviation and related tourism before Covid-19 hit the industry. Of this, 11.3 million people worked directly in the aviation industry [1]. Worldwide, flights produced 915 million tons of CO2 in 2019. Globally, humans produced over 43 billion tons of CO2. In 2019, 4.5 billion passengers were carried by the world's airlines. Nearly 88 million jobs were supported worldwide in aviation and related tourism before Covid-19 hit the industry. Of this, 11.3 million people worked directly in the aviation industry. The global aviation industry produces around 2% of all human-induced carbon dioxide (CO2) emissions. Aviation is responsible for 12% of CO2 emissions from all transports sources, compared to 74% from road transport [2].

While air transport carries around 0.5% of the volume of world trade shipments, it is over 35% by value – meaning that goods shipped by air are very high value commodities, often times [1] perishable or time-sensitive. Deliveries of fresh produce from Africa to the UK alone supports the livehoods of 1.5 million people, while producing less CO2 than similar produce grown in the UK, despite the energy used in transport. Jet aircraft in service today are well over 80% more fuel efficient per seat kilometer than the first jets in the 1960s.Alternative fuels [1], particularly sustainable aviation fuels (SAF), have been identified as excellent candidates for helping achieve the industry climate targets. SAF derived sources such as algae, jatropha, or waste by-products have been shown to reduce the carbon footprint of aviation fuel by up to 80% over their full lifecycle. Around 80% of aviation CO2 emissions are emitted from flights of over 1,500 kilometers, for which there is no practical alternative mode of transport. Globally, the average occupancy of aircraft is **82%,** greater than other forms of transport.

4.2 Air Pollution

Air Pollution In 1993, aircraft emitted 350 million pounds of VOCs and NOX during landing and takeoff cycles, more than double 1970 levels, according to the NRDC report. These two classes of compounds are precursors of ground-level ozone, which can interfere with lung function. "During the summer... between 10% and 20% of all East Coast hospital admissions for respiratory problems may be ozone-related," says the NRDC report. Airports are among the greatest sources of local air pollution. A major airport's idling and taxiing planes can emit hundreds of tons of VOCs and NOX annually. John F. Kennedy International Airport is the second largest source of VOCs in New York City. LaGuardia is among the major sources of NOX [2]. The VOCs emitted by airports may comprise a variety of toxic chemicals, according to a 1993 study by the EPA.

Chicago's Midway Airport released more benzene and formaldehyde than most Chicago factories. Similarly, a 1991 study by Argonne National Laboratory [2], funded by the FAA, concluded that "the impact of airport emissions on the surrounding air quality was not significantly larger than that of the background emissions. This implies that on a per-unit area of ground surface basis, the airport emissions are roughly comparable to those of the surrounding urban/suburban areas and roadways." And, in fact, ground access vehicles such as passenger cars and buses just entering and leaving airports often exceed airplanes as the dominant sources of air pollution at airports. Nationally, ground access vehides emit 56% of VOCs, while aircraft taking off and landing give off only 32.6% (induding emissions from APUs), according to the EPA [3].

4.3 Methods for reducing the amount of noise in the engine under study

Noise Pollution Studies suggest that noise may harm health. Those who say they are bothered by local noise levels rate their general health more poorly than those who say they are not bothered by local noise, according to a study of two comparable communities in New York City, one of which is located in a flight pattern. Arline Bronzaft, professor emeritus of psychology at Lehman College in New York City and author of the study to be published in Environment and Behavior, urges caution in drawing conclusions from the study, however, because of its small size (270 subjects). Noise also may interfere with learning [2].

In a 1975 Environment and Behavior study of children who attended a school situated beside some railroad tracks, Bronzaft found that students who spent the entire six years of elementary school on the side of the school closest to the tracks were a full year behind students who had spent the entire six years on the quieter side facing away from the tracks. After later becoming a consultant to the New York City Transit Authority, Bronzaft was able to get that agency to install a noise abatement system on the tracks. She later retested the children and found that the reading level had become identical on both sides of the building. Yet another reported health impact of noise is increased anxiety and levels of annoyance. For example, during the late 1980s, capacity problems forced rerouting of air traffic around New York City and Newark, New Jersey[3]. Routes above areas surrounding those cities had to be layered four-deep in the vertical plane. Planes suddenly began passing 7,000-8,000 feet over the Catskill Mountains on their way into Newark International Airport, about 100 miles south. Major citizen protests ensued.

4.4 Reducing the chance of engine breakdown and subsequent fuel drain

Airplanes emit huge amounts of carbon dioxide and water vapor, nitrogen oxides and soot into the atmosphere. The environmental impact of these components depends on the flight altitude.

The fact that airplanes pollute the environment with their exhaust gases is obvious and beyond doubt. Yes, in fact, any human economic activity damages nature and contributes to climate change[3]. The only question is how great is the contribution of one kind or another to this general process. Other chemicals besides glycols that are used at airports may get into waterways, but information about these is sketchy. At Kennedy Airport, there are two underground lakes of jet fuel, estimated to contain 3-5 million and 6-9 million gallons, respectively, according to the NRDC report. The New York State Department of Environmental Conservation has ordered the airport to remove the fuel[3]. But glycols receive the most attention. Ethylene glycol is both more effective and more toxic than propylene glycol. The lethal dose for humans of ethylene glycol is a little over three ounces, according to a report prepared for the EPA. Less can damage kidneys. Propylene glycol is relatively innocuous. However, both ethylene glycol and propylene glycol consume high levels of oxygen during decomposition, according to the Airports Council

International, a trade group in Washington, DC. This can deplete waterways of oxygen and kill fish. The NRDC complains that regulations for disposal of deicing chemicals lack teeth.

4.5 Implementation of our developments in the protection of the environment

The CO2 emissions that affect the global climate, and emissions that affect local air quality are expected to increase through 2050, but at a rate slower than aviation demand. Under an advanced aircraft technology and moderate operational improvement scenario, from 2030, aircraft noise exposure may no longer increase with an increase in traffic [4]. However, it has to be kept in mind that the uncertainty associated with future aviation demand is notably larger than the range of contributions from technology and operational improvements. International aviation fuel efficiency is expected to improve through 2050, but measures in addition to those considered in this analysis will be required to achieve ICAO’s 2 per cent annual fuel efficiency aspirational goal. Sustainable alternative fuels have the potential to make a significant contribution, but sufficient data are not available to confidently predict their availability over the long term. Also, considering only aircraft technology and operational improvements, additional measures will be needed to achieve carbon neutral growth relative to 2020 [4].

The storm water pollution prevention plans (SWPPPs) required of states under the Clean Water Act should greatly reduce contaminated storm water discharges from airports if implemented as required, according to the NRDC report. But, the report continues, "It is not clear when, or if, the plans will be inspected by a regulatory agency." they have no authority to make a final determination of what those standards are.

A small number of airports are very successfully recapturing glycols following use. According to the Airports Council [4].

At the Denver airport, which was designed to optimize collection of glycols, 65-70% of the fluid is recaptured, says Carter. These glycols are concentrated to a relatively high 25% on average, depending on the duration and nature of the precipitation. Recyclers increase the concentration to as high as 99.5%. "We recycle it for coal companies, some paint manufacturers, and General Motors," says Carter. But in the United States, recycled glycols are never used for de-icing, unlike in Europe [4]. "The American manufacturers of glycol have convinced the U.S. airlines that it is a liability to use recycled glycol, although the same airlines use it in Europe all the time," says Carter. A technological fix that could render de-icing chemicals partially obsolete is the use of infrared rays to heat the exterior of the plane. In such a process, immediately before takeoff the plane would pull into a hangar-like structure outfitted with the infrared energy process units and park there for approximately six minutes while the de-icing takes place.

4.6 Reducing pollution using our research

Let`s reduce air pollution, by reduce fuel consumption. We can cooling compressor blades and decrease air bleed. This provide best efficiency coefficient, which effects on fuel consumption.

At first, calculations without changes:

Initial data of calculation:

$L_c = 312395.811 \quad \frac{J}{kg}$

$g_t = 0.018$

$R_g := 288$

$P^*_t = 291097 \quad Pa$

Air bleeding $g_{cool} := 0.04$ mechanical efficiency of the turbine $\eta_M := 0.985$

$$L_t := \frac{L_c}{(1 + g_t) \cdot (1 - g_{cool}) \cdot \eta_M} = 324443.482 \quad \frac{J}{kg}$$

Turbine efficiency $\eta^*_t := 0.9$ and find the temperature and pressure behind the turbine

$P^*_{t.c} := 1.1 \cdot P_H = 111430 \quad Pa$

$k_g - 1 \quad L_t \qquad 1.33 - 1 \quad 324443.48193805467$ $= 973.5 = 973.5\ K$

Specific power transmitted to the propeller from the turbine

$L_{spec} := L_{free.t} \quad \frac{J}{kg}$

$N_{spec} := L_{spec} \cdot (1 + g_t) = 217097.696 \quad BT$

$04.581 \quad \frac{J}{kg}$

Equivalent power $N_e := 1660000 \quad BT$

Air consumption through TSE (TurboShaft Engine)

$$G_{consump} := \frac{N_e}{N_{spec}} = 7.646 \quad \frac{kg}{H \cdot hour}$$

$$G_T := 3600 \cdot G_{consump} \cdot (1 - 0.04 - 0) \cdot g_t = 482.533 \quad \frac{kg}{H \cdot hour}$$

Second stage – calculation with compressor blades cooling and air bleed decrease:

Initial data:

$g_t = 1.0140.018$

$R_g := 288$

$P^*_t = 1 \cdot 29109 \text{ Pa}$

Air bleeding $g_{cool} := 0.06$ mechanical efficiency of the turbine $\eta_M := 0.96$

$$L_t := \frac{L_c}{(1 + g_t) \cdot (1 - g_{cool}) \cdot \eta_M} = 1 \cdot 324443.482 \ \frac{J}{kg}$$

Turbine efficiency $\eta^*_t := 0.8$ and find the temperature and pressure behind the turbine

$P^*_{t.c} := 1.1 \cdot P_H = 1 \cdot 111430 \ \text{Pa}$

$$T^*_t := T^*_g - \frac{k_g - 1}{k_g} \cdot \frac{L_t}{R_g} = 1973.5K$$

$$L_{free.t} := \frac{k_g}{k_g - 1} \cdot R_g \cdot T^*_t \cdot \left[1 - \left(\frac{P^*_{t.c}}{P^*_t}\right)^{\frac{k_g - 1}{k_g}}\right] \cdot \eta^*_{free.t} = 1 \cdot 213204.581 \ \frac{J}{kg}$$

Specific power transmitted to the propeller from the turbine

$L_{spec} := L_{free.t} \ \frac{J}{kg}$

$N_{spec} := L_{spec} \cdot (1 + g_t) = 0.886 \cdot 245097.696 \ \text{BT}$

Equivalent power $N_e := 1810000 \ \text{BT}$

Air consumption through TSE (TurboShaft Engine)

$$G_{consump} := \frac{N_e}{N_{spec}} = 1.1516.646 \ \frac{kg}{H \cdot hour}$$

$$G_T := 3600 \cdot G_{consump} \cdot (1 - 0.04 - 0) \cdot g_t = 1.045 \cdot 461.74 \ \frac{kg}{H \cdot hour}$$

As we can see from calculations, we reduced fuel consumption from 482.533 kg/(H*h) to 461.74 kg/(H*h).

4.7 ICAO CO2 certification requirement

In February 2013, ICAO's environmental committee finalized a CO2 certification requirement to serve as the basis for a global CO2 (efficiency) standard for new aircraft. Under the requirement, the CO2 intensity of new aircraft will be evaluated at three steady-state cruise test points, with aircraft required to meet efficiency targets set as a function of their maximum takeoff mass (MTOM) after correcting for the floor area of the aircraft. This approach is expected to rank the CO2 intensity of new commercial aircraft in proportion to emissions per seat kilometer flown, can be used to set a standard via a single continuous line, and should be inexpensive for manufacturers to certify as it is patterned on existing data gathering practices. Disadvantages of the procedure include its failure to measure non-cruise fuel burn, the use of flight conditions unrepresentative of day-to-day operations, providing no direct crediting for lightweight materials, and uncertainty about whether some future technologies to reduce fuel burn will be accurately characterized under the procedure.

CO2 certification requirement

Following three years of work, the International Civil Aviation Organization's (ICAO) Committee for Environmental Protection (CAEP) finalized a carbon dioxide (CO2) certification requirement, including metrics, fuel efficiency test points, and detailed certification procedures, to be added as a new volume to Annex 16 of ICAO's Convention on International Civil Aviation.

Further information regarding each of these components is provided below. Metric Specific air range, or SAR1 , is a commonly used metric in the aviation industry to measure cruise fuel burn. SAR is typically measured in units of km traveled per kg of fuel, and was inverted for the purposes of the certification requirement such that a reduction in the CO2 intensity of an aircraft would be reflected as a reduction in the metric score.

Commercial turbofan aircraft – regional jets in purple, single aisle aircraft in red, and twin aisle aircraft in black – will have their CO2 intensity measured at between 30,000 and 42,000 feet, while business jets, which are designed to cruise at higher altitudes, will be tested above 40,000 feet. Service ceiling limited aircraft, notably turboprops but also some smaller business jets, would have their CO2 intensity certified at a single pressure altitude but multiple cruise speeds, which are not shown in the diagram.

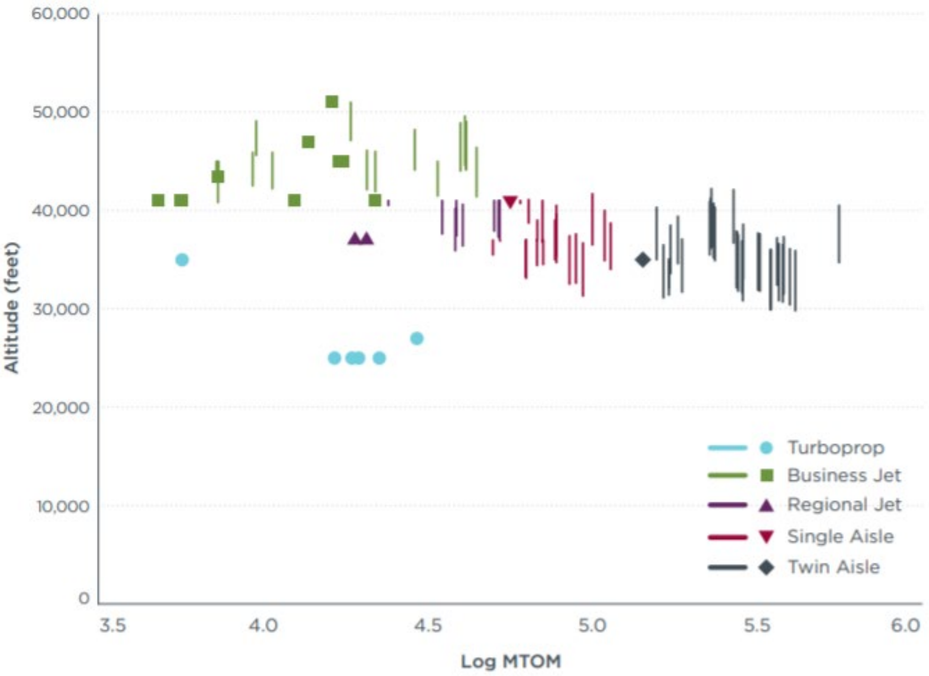


Figure 4.1: Pressure altitudes for CO2 intensity testing

Source: ICCT, using PIANO-X database.

Figure2 plots metric scores for representative in-production (blue) and older out of production (red) aircraft types as a function of their MTOM. As the blue and red regression lines on the figure demonstrate, the metric system is able to distinguish between different aircraft generations, a key test for a metric system designed to promote efficiency technologies. Over time, as technology advances and the standard becomes more stringent, the standard line will fall and flatten out, as demonstrated the different between the in- and out-of-production lines in Figure 2.

In addition to technology, this metric system provides the potential for manufacturers to comply with CO2 requirements through non-technical means, notably changes in certified MTOM. Because many operational expenses, including airport landing fees and en route charges, are levied as a function of MTOM, manufacturers today typically sell a given aircraft model under various MTOMs ("paper" variants), corresponding to differing nominal payload-range capabilities.

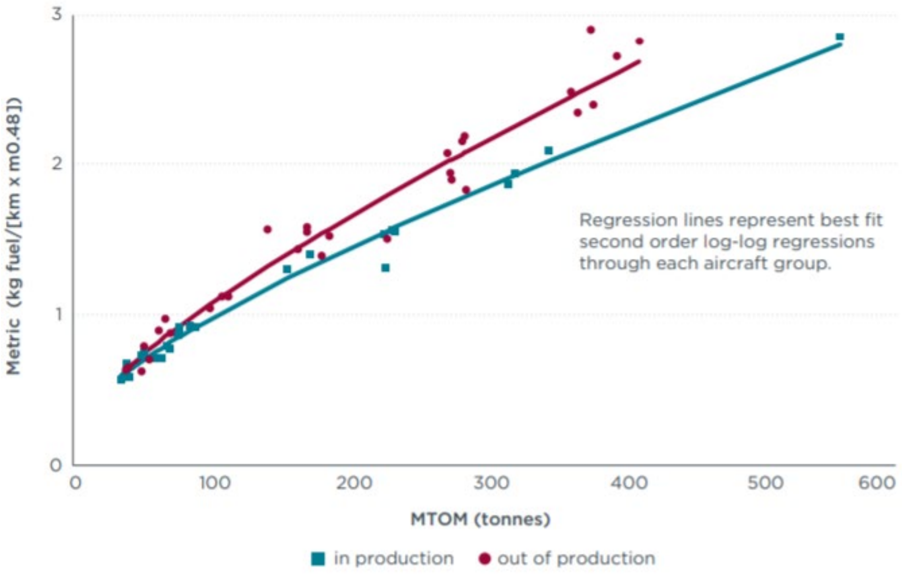
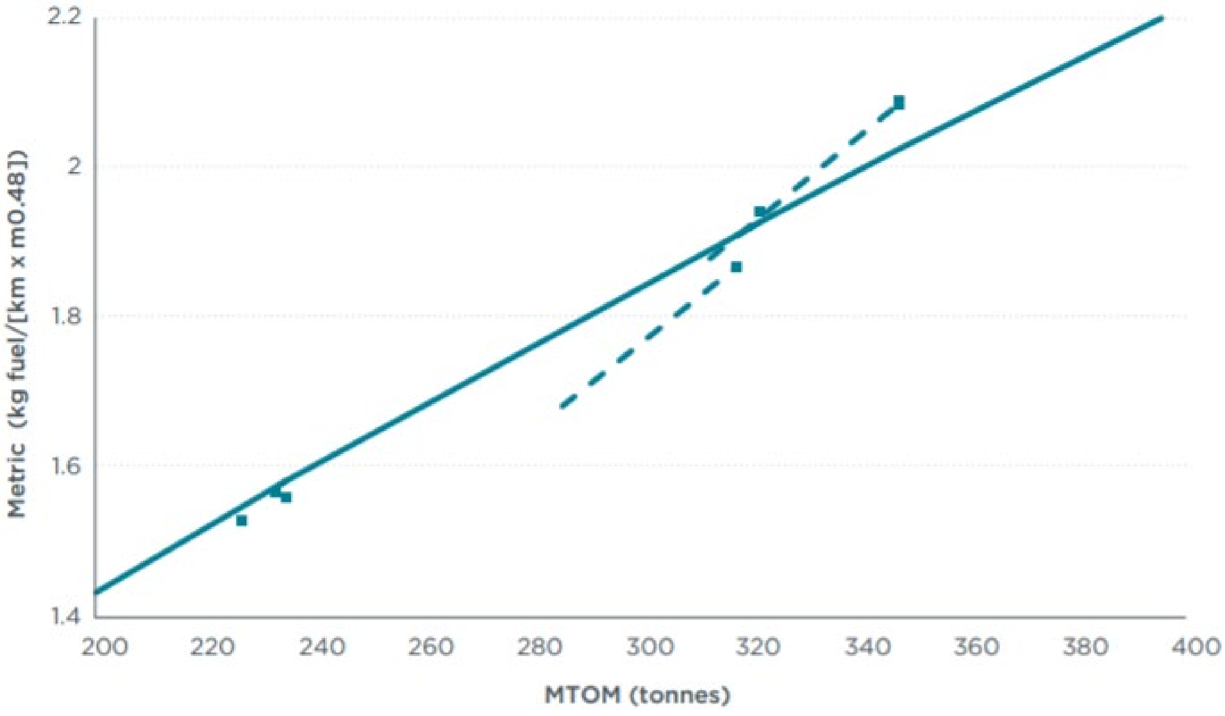


Figure 4.2: Metric scores for relevant in and out-of-production aircraft Source: ICCT, using PIANO-X database.

This allows airlines not requiring an aircraft's maximum payload-range capability to reduce operational expenses by purchasing a lower MTOM variant.

Under ICAO's CO2 certification requirement, low MTOM variants of most aircraft will score better on the standard than higher MTOM variants. This is demonstrated in Figure 3, which shows the in-production aircraft data presented in Figure 2 between 200 to 400 tonnes MTOM along with dotted lines representing a



10% MTOM “paper” reduction for two aircraft types. As the figure shows, the slope of the lines denoting the MTOM paper change is steeper than that of the overall fleet regression line, meaning that a manufacturer can increase the margin of a given aircraft type to the standard through a MTOM paper reduction.

Figure 4.3: MTOM “paper” changes under a CO2 standard

For this reason, it will be possible for manufacturers to make aircraft comply with the CO2 standard without incremental investments in fuel efficiency technology by lowering the range of MTOMs at which they are marketed. These lower paper MTOM variants, while nominally complying with the standard, will have identical emissions to higher, non-compliant MTOM variants when used in service. As a rule of thumb, a 5% paper MTOM reduction, which would have marginal impacts on revenue and aircraft values, should provide an additional 1.5% margin to a standard.

Conclusion

ICAO’s CO2 certification requirement has certain merits. As noted above, the metric system is capable of distinguishing different aircraft technology levels, and is expected to rank the efficiency of commercial aircraft, which are responsible for the vast majority of civil aviation fuel use and CO2 emissions, in rough proportion to emissions per seat kilometer flown. The metric system can be used to set a CO2 standard via a single continuous line, reducing the opportunity for gaming through means such as corner effects or reclassifying a given aircraft as a different type in order to gain access to a weaker standard. Finally, it should be inexpensive for manufacturers to certify their aircraft to the standard because the certification requirement is built upon industry practices already used by manufacturers to collect fuel burn data for airlines.

Conclusions for part 4

In this part, consider the impact of aviation on environmental pollution, types of pollution, methods of protection against them.

Introduced developments to reduce fuel consumption, which, as a result, will decrease an emissions of pollutants into the atmosphere.

Considered ICAO CO2 certification requirement for Aviation industry pollution.

PART 5

LABOUR PROTECTION

5.1 Introduction

Labor protection is a system of preserving the life and health of workers in the process labor activity, including legal, socio-economic, organizational and technical, sanitary and hygienic, treatment and prophylactic, rehabilitation and other activities.

Legal measures for labor protection are to create a system legal norms establishing standards for safe and healthy working conditions and legal means to enforce them.

5.2 Analysis of working conditions

Working conditions are at the core of paid work and employment relationships. Generally speaking, working conditions cover a broad range of topics and issues, from working time (hours of work, rest periods, and work schedules) to remuneration, as well as the physical conditions and mental demands that exist in the workplace.

The ILO (International Labor Organization) monitors trends and developments regarding working time, work organization, and work-life balance around the world and analyses key and emerging issues, in order to provide ILO constituents and policymakers with practical information and research-based policy advice grounded in state-of-the-art knowledge. In addition, the ILO seeks to collaborate with national research institutes and academic institutions to obtain the state-of-the-art knowledge needed to support workers and employers in developing and implementing balanced working time arrangements that can protect workers' health, benefit their well-being and work-life balance, and promote sustainable enterprises as well.

Harmful production factor is a production factor, the impact of which on an employee can lead to his illness (unfavorable microclimate, increased noise, vibration, poor lighting, unfavorable air ionic composition of the air).

Hazardous production groups of factors:

Physical factors - moving machines and mechanisms, increased levels of noise and vibration, electromagnetic and ionizing radiation, insufficient illumination, increased levels of static electricity, increased voltage in the electrical circuit, etc.

Chemical factors are substances and compounds that differ in their state of aggregation and have toxic, irritating, carcinogenic and mutagenic effects on the human body and affect its reproductive function.

Biological factors - pathogenic microorganisms (bacteria, viruses, rickettsiae, spirochetes) and their waste products, as well as animals and plants.

Psychophysiological factors - factors of the labor process. These include physical (static and dynamic overload) and neuropsychic overload (mental overstrain, overstrain of analyzers, monotony of work, emotional overload).

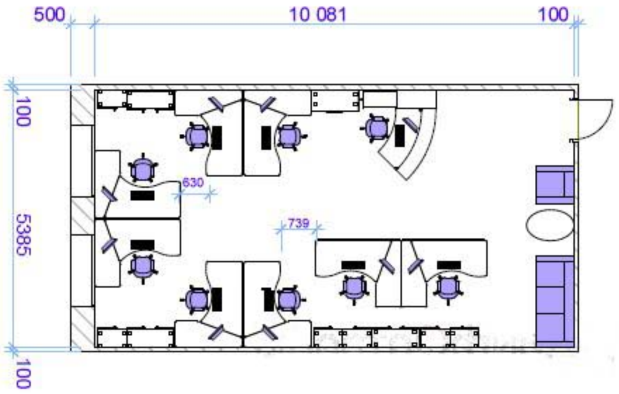
5.2.1 Workplace organization

Workplace - a place of permanent or temporary residence of an employee during the performance of his job duties, directly or indirectly under the control of the employer. A permanent workplace is one in which an employee spends half or most of his working time (more than two hours continuously). If, under these circumstances, work is performed in different parts of the working area, then the entire area is considered a permanent place.

Lets consider our working room:

A=a*b

A=10*5=50 (meters per square)



Where «a» is width «b» is length

The working area for a one person is equal:

$$A_{person} := \frac{A}{n} = \frac{50}{5} = 10 \ m^2$$

Room is equipped of two ceiling lights and two windows. It has seven standard sockets, it has fire extinguisher. Also ventilation is available, the average temperature in room is 24 degrees.

5.2.2 The list of harmful and hazardous factors

Hazardous and harmful factors are:

Physical hazardous and harmful production factors are: unsatisfactory microclimate (temperature, humidity, air ventilation, infrared or ultraviolet radiation) in the room; barometric pressure; constant electric fields and radiation; hazardous ionizing radiation; high level of industrial noise and vibrations (local or general); insufficient natural or technical lighting in work areas.

Chemical hazardous and harmful production factors include organic and inorganic substances and their compounds.

Biological factors are microbes, fungi, products of microbiological synthesis (feed yeast, antibiotics, hormones, plant protection products), etc.

Psychophysiological factors include: emotional stress (caused, for example, by excessive stress on the central nervous system, sensory organs); dynamic and static overloads; forced position of the body when performing various production operations; excessive and prolonged pressure of various objects on the limbs and other parts of the body, overloading of individual body systems; insufficient physical activity; excessively fast pace of work.

5.2.3 Analysis of harmful and dangerous production factors

illumination

For general and local lighting of premises it is necessary use light sources with color temperatures from 2400 K to 6800 K. The intensity of ultraviolet radiation in the spectral range 320-400 nm should not exceed 0.03 W / m2 Radiation with a wavelength less than 320 nm is not allowed.

The most energy-efficient light sources should be used for general artificial lighting of premises, preferring light sources with higher light output and service life at the same power with the requirement not to reduce the quality of lighting equipment for reduction of energy consumption. (ДБН В.2.5-28:2018)

Noise and vibration levels

Sanitary norms apply to noise, infra- and ultrasound transmitted through air (gaseous medium), liquid or solid medium and affect the person in the process labor activity.

Sanitary norms establish:

- classification of production acoustic oscillations;
- methods of hygienic assessment of industrial noise, ultrasound and infrasound;
- parameters that are normalized and their allowable values;
- requirements for measurements at workplaces.

Sanitary standards are mandatory for all ministries, departments, enterprises, institutions, regardless of departmental affiliations and forms of ownership, citizens who design, manufacture and operate equipment, mechanisms and tools, which are sources of noise, ultrasound and infrasound; who develop and implement measures to reduce the harmful effects of acoustic fluctuations in workers; who perform state sanitary supervision under working conditions. (ДСН 3.3.6.037-99)

Permissible sound levels, equivalent sound levels and sound pressure levels in octave frequency bands	
Type of work, work places	Sound pressure levels in decibel
	In octave bands with geometric mean frequencies, Hz

	31,5	63	125	250	500	1000	2000	4000	8000	Sound levels, equivalent sound levels, dBA / dBAeq.
Programmers	86	71	61	54	49	45	42	40	38	50
Operators in information processing rooms on PC	96	83	74	68	63	60	57	55	54	65
In rooms for noisy units	103	91	83	77	73	70	68	66	64	75

Non-ionizing electromagnetic radiation

Sanitary norms and rules (hereinafter - the Rules) of protection of the population from the effects of EMF, created by radio facilities, hereinafter (PTO), determine the hygienic requirements for transmitting radio, television stations and other facilities that emit electromagnetic energy into the environment. The rules apply to existing housing, buildings being designed and constructed, individual residential, public and industrial buildings of various departments, public recreation areas located in areas where both existing (PTO)s and those designed and constructed.

Responsibility for compliance with these Rules rests with ministries, departments, agencies, organizations, enterprises, cooperatives and other legal entities and individuals who operate, reconstruct or design in Ukraine (PTO), or individual transmitting devices that emit electromagnetic energy.

Electromagnetic energy emitted by the antennas of transmitting (PTO), propagates in space, forming an EMF, which is characterized by two inextricably linked components: electrical (E) and magnetic (H).

The electromagnetic field in 5-8 frequency ranges is estimated by the field strength. The unit of field strength for the electrical component is volts per meter (V/m).

Nomenclature of frequency ranges (waves)

Range number	Frequency range (excluding lower, including upper limit)	Wave range (excluding lower, including upper limit)	Appropriate metric distribution of ranges

5	from 30 to 300 kHz	from 10^4 to 10^3 м	Kilometer waves (low frequencies)
6	from 300 to 3000 kHz	from 10^3 to 10^2 м	Hectameter waves (medium frequencies)
7	from 3 to 30 MHz	from 10^2 to 10 м	Decameter waves (high frequencies)
8	from 30 to 300 MHz	from 10 to 1 м	Meter waves (very high frequencies)
9	from 300 to 3000 MHz	from 1 to 0,1 м	Decimeter waves (ultrahigh frequencies)
10	from 3 to 30 GHz	from 10 to 1 см	Centimeter waves (ultrahigh frequencies)
11	Від 30 до 300 ГГц	from 1 to 0,1 см	Millimeter waves (extremely high frequencies)

5.2.4 Microclimate of the working place

The microclimate of industrial workspaces is the meteorological conditions of the internal environment, determined by the combinations of temperature, relative humidity and air velocity acting on the human body, as well as the temperature of the surfaces of enclosing structures and technological equipment.

Season	**Category of works**	**Air temperature, deg. C**	**Relative humidity, %**	**Air velocity, m/s**
		optimal	**optimal**	**optimal**
cold	easy-1 a	22 – 24	40 – 60	0,1
	easy -1 б	21 – 23	40 – 60	0,1
warm	easy -1 a	23 – 25	40 – 60	0,1
	easy -1 б	22 – 24	40 – 60	0,2

5.2.6 Non-ionizing electromagnetic fields and radiations

State sanitary norms and rules when working with sources of electromagnetic fields (hereinafter - sanitary standards and rules) establish requirements for working conditions of employees that engaged in the manufacture, operation, maintenance and repair of equipment, during the operation of which there are permanent magnetic fields (hereinafter - EMF) and electromagnetic radiation (hereinafter - EMR) in frequency range from 50.0 Hz to 300.0 GHz.

These sanitary norms and rules do not apply to employees working with visual display terminals computers or perform work in the off electrical installations with voltage up to 750 kV inclusive. Sanitary norms and rules are mandatory for all ministries, other central executive bodies, enterprises, institutions, organizations, regardless of departmental affiliations and forms of ownership, citizens who design, manufacture, operate and maintain equipment, apparatus, devices, equipment, etc., which are sources of EMF, which develop and

implement measures to reduce the harmful effects of EMF on workers who perform state sanitary supervision under the conditions labor.

5.2.7 Production noise, ultrasound, infrasound

Sanitary norms apply to noise, infra- and ultrasound transmitted through air (gaseous medium), liquid or solid medium and affect the person in the process labor activity.

Sanitary norms establish:

- classification of production acoustic oscillations;
- methods of hygienic assessment of industrial noise, ultrasound and infrasound;
- parameters that are normalized and their allowable values;
- requirements for measurements at workplaces.

Sanitary standards are mandatory for all ministries, departments, enterprises, institutions, regardless of departmental affiliations and forms of ownership, citizens who design, manufacture and operate equipment, mechanisms and tools,

which are sources of noise, ultrasound and infrasound; who develop and implement measures to reduce the harmful effects of acoustic fluctuations on workers; who perform state sanitary supervision under working conditions. The requirements of these rules must be taken into account regulatory and technical documents: standards, building codes, technical conditions, instructions, guidelines, etc., which regulate design and operational requirements for machines, equipment, machinery and tools, technological processes and regulations, foreign products that are sources of noise, ultra- and infrasound in production conditions.

5.3 Engineering technical and organization solution to prevent the effect of hazardous and harmful production factors

Everyone has the right to adequate, safe and healthy working conditions. This is guaranteed by the Constitution of Ukraine (Part 4 of Article 43). More detailed requirements for labor protection, in particular labor protection of office workers, include the Code of Labor Laws, the Law of Ukraine "On Labor Protection", as well as other bylaws. In accordance with the requirements of Art. 153 of the Labor Code of Ukraine and Art. 6 of the Law of Ukraine "On labor protection" at all enterprises, institutions, organizations create safe and harmless working conditions. Ensuring safe and harmless working conditions is the responsibility of the owner or his authorized body.

Working conditions at the workplace, safety of technological processes, machines, mechanisms, equipment and other means of production, the state of collective and individual protection used by the employee, as well as sanitary conditions must meet the requirements of labor protection regulations. The owner or his authorized body must implement modern safety measures to prevent occupational injuries and provide sanitary and hygienic conditions to prevent occupational diseases of workers. Article 158 of the Labor Code of Ukraine establishes the obligation of the owner or his authorized body to take measures to facilitate and improve working conditions of workers through the introduction of advanced technologies, advances in science and technology, mechanization and automation of production, ergonomics, positive experience in labor protection, reduction and elimination of dust and gassiness of air in industrial premises, reduction of intensity of noise, vibration, radiation, etc. And according to part 1 of Art. 13 of the Law of Ukraine "On labor protection" the employer is obliged to create working conditions in the workplace in each structural unit in accordance with regulations, as well as to ensure compliance with legislation on workers' rights in the field of labor protection.

Workplaces of office workers equipped with personal computers (hereinafter - workplaces) must meet the requirements of the "Rules of labor protection during operation of electronic computers", approved by the Order of the State Committee of Ukraine for

Industrial Safety, Labor Protection and Mining Supervision of 26.03. 2010 № 65 (Rules), and “State sanitary rules and norms of work with visual display terminals of electronic computers”, approved by the resolution of the Chief State Sanitary Doctor of Ukraine dated 10.12.98 N 7 (DSanPiN 3.3.2-007-98).

5.4 Fire safety of production facilities

1. Fire safety activities are a component of production and other activities of officials and employees of enterprises and facilities.

2. The head of the enterprise is obliged to take on the relevant responsibilities of officials to ensure fire safety, the importance of fire safety without individual buildings, structures, premises, sections, technological and engineering equipment, as well as maintenance and operation of fire protection.

Responsibilities for fire safety, maintenance and use of fire protection are provided in job descriptions, responsibilities, regulations of the unit.

3. In another facility, the relevant document (order, instruction, etc.) must establish a fire regime, which includes:

the procedure for maintaining evacuation routes;

determination of a special place for smoking;

the procedure for using open fire;

the procedure for using household heating appliances;

the procedure for conducting temporary fire-hazardous works;

rules of travel and parking of vehicles;

places for storage and admissible quantity of raw materials, semi-finished products and finished products which can be at the same time in premises and in the territory;

the procedure for cleaning combustible dust and waste, storing oiled overalls and rags, cleaning the elements of ventilation systems from combustible deposits;

the procedure for disconnecting equipment and ventilation systems from the power supply in case of fire;

the order of inspection and closing of premises after the end of work;

the procedure for training and testing of knowledge on fire safety by officials, as well as conducting firefighting briefings for employees and establishing a fire-technical minimum with the appointment of appropriate for their conduct;

the order of organization and maintenance of available means of counter-protection;

the procedure for carrying out planned and preventive repairs and inspections of electrical installations, heating, ventilation, technological and other engineering equipment;

the procedure for gathering members of the fire and rescue unit of voluntary fire protection and officials responsible for fire safety in case of fire, call at night, on weekends and holidays; (НАПБ А.01.001-14.)

5.5 Calculation for choose battarey of heating

The first thing you need to know to calculate is the volume of your room. We multiply the length and width by the height (in meters) (5 * 10 * 2.7) - and we get the 135 m^3. This is the volume of the room in cubic meters.

Second: to heat one cubic meter in a standard building (without metal-plastic windows, foam insulation, etc., energy-saving measures) in the climatic conditions of Ukraine, 41 W of thermal power is required.

We find out how much heat we need, for this we multiply our volume V by the number 41:

V * 41 = 135 *41 Вт = 5535 Вт.

The resulting figure is the amount of heat that radiators must give in order to heat up your room. Let's round it up to 5500.

Any batteries on the package or in the complete insert has information about the heat output. Thermal power is the amount of heat that a radiator can give off when cooled from a heating temperature to room temperature - 20 degrees Celsius.

For reliability, it is worth increasing the resulting figure by 20 percent. To do this, multiply 5500 by a factor of 1.2 - we get approximately 6600.

Conclusions for part 5

In part 5 was considered labor protection like a system of preserving the life and health of workers in the process labor activity, including legal, socio-economic, organizational and technical, sanitary and hygienic, treatment and prophylactic, rehabilitation and other activities.

Considered influence of harmful and dangerous production factors like production noise, ultrasound and infrasound on work efficient. Solved the problem of choosing the optimal heat source for the workplace.

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