PARALLEL SYSTEM INFORMATION MODEL DIAGNOSTICS AND FORECASTING OF TECHNICAL CONDITION OF AIRCRAFT

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To date, there is a contradiction between the ever-growing need to increase the degree of functional saturation of diagnostic tools and forecasting the current state of aircraft and the limited technical capabilities of diagnostic tools. The noted contradiction is constantly aggravated due to the ever-increasing complexity of aircraft and means of their automation, which requires a corresponding increase in the functionality of the means of monitoring the technical condition. All this leads to an unjustified increase in the weight and size indicators of diagnostic tools, which significantly affects the technical and economic indicators during the operation of aircraft. This article proposes an information model for a parallel system for diagnosing and predicting the technical condition of aircraft using the example of helicopters, characterizes the groups of sensors included in the system, and outlines the principles for solving problems of diagnosing and predicting the failure state of an aviation complex. A procedure is proposed for accumulating flight data on the parameters of critical components and assemblies on board a helicopter and a method of express analysis, which consists in monitoring in real time the trend of parameters and the rate of change of this trend to limit values. It has been proven that provision should be made for the issuance of emergency visual and audible indication to the helicopter crew about an emergency situation.

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Introduction

The development of modern civil aircraft is characterized by a rapid increase in the degree of functional saturation, due to the expansion of the range of tasks to be solved. In modern civil aviation, this is due to the widespread introduction of automation tools for flight and landing control processes in conditions of increased flight traffic, including in urbanized areas.

The successful solution of problems associated with complex systems for diagnostics and prognostics of the technical condition of aircraft in modern conditions should be based on the concept of a systems approach. The essence of this approach is the step-by-step implementation of procedures for the synthesis of diagnostic systems and prognostics of the technical condition of the aviation complex, starting with the procedure of structural synthesis and ending with parametric synthesis and the development of highly efficient real-time computing systems (RTCS).

Materials and research methods

At the stage of development and testing of real-time computing systems (RTCS), a number of problems arise, the solution of which requires not only appropriate software tools, but also the necessary instrumental support [1-3]. These tasks include:

- verification of the compliance of the RTCS with the specified requirements for information exchange, including in terms of receiving and transmitting data via external interfaces;
- working out the interaction between the individual computers of the RTCS through the onboard data transmission channels;
- complex testing and debugging of algorithmic and software of the RTCS;
- evaluation of the reliability of the architecture of the RTCS, including the presence of a reserve in the throughput of data transmission channels and the stability of the hardware and software of the RTCS to failures during data transmission;
- construction of schedules for the exchange of data via onboard channels, as well as checking the correctness of the processing of this schedule by individual calculators as part of the RTCS.

The development process of an RTCS, as a rule, presupposes the presence of a stage of creation and testing of a prototype (prototype) sample [4-8, 19]. All of the above tasks, from checking the operability of circuit solutions of the RTCS and ending with the stage of debugging its algorithmic and software, represent one of the most laborious and critical stages in the design process of the RTCS.

Providing the process of solving the above tasks with the necessary information of a given volume and quality cannot be achieved only by using real objects of control (aircraft) due to the lack of the possibility of creating a wide range of emergency situations. For example, it is impossible to perform a flight with failed components or transmission units of a helicopter, because such a flight will inevitably lead to a catastrophic situation. On the other hand, the use of only electronic modeling methods requires excessive labor costs for intellectual activity and still will not provide the required similarity of the controlled systems in a particular failure or pre-failure situation. Therefore, a full-fledged solution of such important problems in the process of development and testing of RTCS is possible with the help of semi-natural modeling methods, which allows you to research, design and test both individual modules of complex technical systems, and the systems themselves as a whole, for which the solution of the above problems by other methods is difficult or impossible. This feature allows you to recreate the necessary conditions for checking the synchronization of the computational process with real time.

Based on the results of semi-natural modeling, the characteristics of the RTCS are refined, and, first of all, the control algorithms incorporated in it. The questions of reliability of the results of diagnostic control and thus the efficiency of the system as a whole are investigated. If necessary, the composition of the measuring equipment and its characteristics are specified, and corrections are made to the test program in real flight conditions on the aircraft. Semi-natural modeling allows you to obtain more reliable information about the behavior of the controlled system than mathematical modeling. This is clear from the fact that a really functioning system or its components and assemblies will always differ in the accuracy of stationary and dynamic parameters characterizing its working processes from the same parameters obtained as a result of mathematical modeling. Firstly, because the calculations and mathematical relationships used in mathematical modeling reflect the real picture of the functioning of the system or its nodes with some assumptions, and, secondly, not all calculated data and workflows can be reproduced in a mathematical model with sufficient reliability for a number of technological factors.

First, a semi-natural simulation should be performed to ensure that the controlled mechanical system is in good working order. Then you can begin to simulate the defects of the mechanical system. When modeling the frequency at which the defect is most noticeably manifested, its harmonics and subharmonics in the spectrum, it is necessary to simulate the process of gradual development of the defect. For this purpose, the increase in the amplitude of the vibration signal at this frequency and its harmonics and subharmonics should be started by increasing it by 3 decibels in comparison with the noise level and then at each step of the study add one decibel. Testing continues until the system under test gives a signal about a noticeable deterioration in the vibration state of the controlled mechanical object [10].

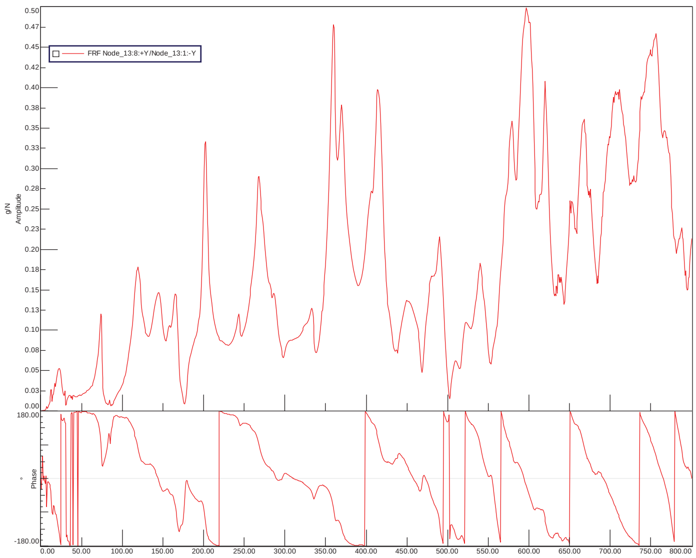

Fig. 1. Amplitude-frequency and phase-frequency characteristics of the helicopter unit, obtained during the semi-natural analysis

For the completeness of the simulation of defects in mechanical systems, testing should be supplemented by the simulation of a change in such an important criterion used in vibration diagnostics as the crest factor. The latter is a vibration signal parameter that cannot be obtained by modeling the spectrum of this signal. The crest factor actually characterizes the degree of wear of the bearings and shafts in the joint with the bearing, as well as the degree of development of cracks in the disk of the gear wheels.

The crest factor P is defined as the ratio of the peak value of the vibration signal Xp to its rms value Xs [11].

$$P = Xp / Xs.$$

To diagnose the vibration state of controlled mechanical systems, the peak factor is periodically measured and changes in this value are monitored during the operation of the mechanical system. Figure 2 shows the characteristic change in the peak factor value as defects develop in the controlled mechanical system.

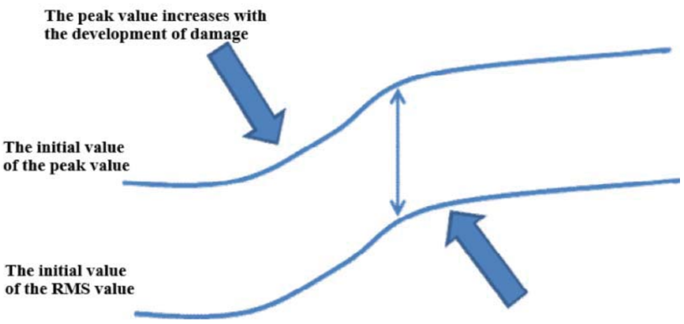

Fig. 2. Change in peak factor values with development mechanical system defects

Simulation modeling of the process of changing the values of the peak factor to simulate the degree of deterioration of the state of the controlled mechanical system can be performed by gradually increasing the value of the average dispersion of the noise component of the vibration signal. In this case, the increase in the peak values of the amplitudes in the time sections at which the root-mean-square value of the vibration signal is calculated should be modeled with a larger coefficient.

The software that solves the problems of diagnostics and forecasting is obliged to recognize a noticeable change in the peak factor of the controlled vibration signal. The task of testing is to determine the threshold level of the crest factor, from which the onboard subsystem informs about the fact of a noticeable deterioration in the vibration state of the controlled mechanical system [12].

Increased wear of the gear teeth in most cases is characterized by an exponential increase in relation to the development of the dispersion of the noise component, therefore, simulation of the vibration signal corresponding to the degree of development of this gear defect should also be performed by increasing the dispersion of the noise signal from the vibration sensor. To impart an exponential character to the increase in the dispersion in the spectrum, the latter should increase sub-rate with each testing of the on-board subsystem.

More complex is the simulation of vibration signals corresponding to the presence of defects in individual teeth, such as chipping, cracks and fractures, in gears. The listed defects of individual teeth are disturbing factors that lead to a change in the shape of the vibration signal by superimposing its modulation, therefore, the simulation of such defects will consist in performing the operation of modulating the vibration signal with a certain frequency.

In this article, we will consider a helicopter as an aircraft. To determine the types of sensors and their orientation on board, it is necessary to specify the type of the helicopter for diagnostics. A specific diagnostic scheme is selected depending on the type of helicopter.

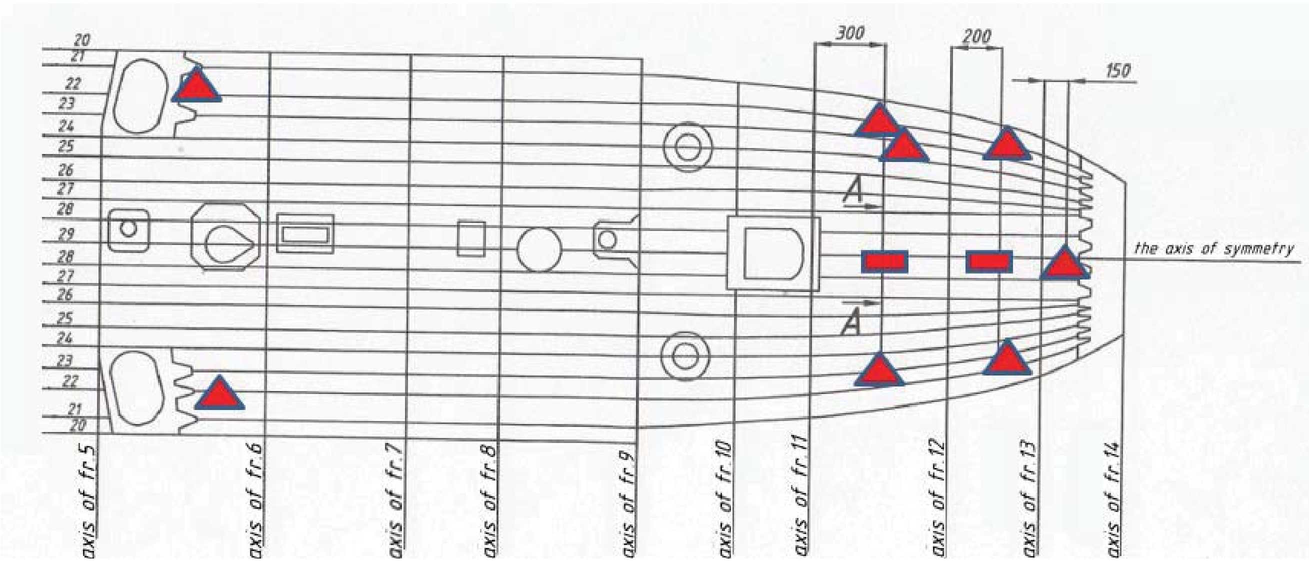

Fig. 3. Location of strain gauges on a fragment of the helicopter airframe: strain gauges for fixing normal and tangential stresses in relation to the construction axis of the helicopter

Initially, it is necessary to define a list of additional sensors for possible types of helicopters:

– he vy helicopter with longitudinal propellers ("classic" aerodynamic configuration);

– heavy helicopter with coaxial propellers;

– light helicopter (with longitudinal or coaxial propellers).

Here is a brief description of the "classical" and coaxial aerodynamic schemes of the helicopter:

– in the classical sche e, a small-diameter propeller is located on the tail of the helicopter. This scheme is considered classic, since it was first proposed by Boris Nikolayevich Yuriev on his aircraft, together with a swashplate. Most of the world's helicopters are built according to this scheme;

– the oaxial scheme is a pair of screws located one above the other on the same shaft. The screws rotate in opposite directions, thus compensating for the reactive moments arising from each of the screws.

Thus, for a helicopter with a coaxial configuration, the transmission modules responsible for the transmission of torque to the tail rotor (tail and intermediate gearboxes) are excluded from the control elements.

In the general case, the choice of the nomenclature of the controlled mechanical units of the helicopter is determined by their purpose, the severity of the consequences in case of failure, testability (physical principles of operation, design features), conditions and operating modes, the predicted level of reliability, as well as the experience of operating prototypes and analogues [13 – 15].

Thus, the following vital mechanical units are defined as objects of technical diagnostics:

– for longitudinal helicopters: main rotor; tail rotor; main gearbox; angular gearboxes; intermediate gearbox; tail gearbox; transmission shafts;

– for coaxial helicopters: upper rotor; lower rotor; column of rotors; main gearbox.

Lists of registered parameters should be formed on the basis of objective control tasks in operating organizations.

The main of these tasks are:

1) control o r the observance of flight and operational restrictions by the crew;

2) control of the correct ss and completeness of the flight missions;

3) monitoring of the operability of aviation equipment systems (AE) in flight (first of all, vital AE systems);

4) control of the correct operation of the AE systems by the crew in flight.

The formation of the lists of parameters should be carried out on the basis of the basic requirements for the solution of the above objectives of objective control. The main such requirement is to ensure high reliability of control results. According to the Russian industry (aviation) standard [26], the probability of obtaining a reliable control result should be at least 0.999. This requirement applies primarily to airborne monitoring systems, but also to ground-based objective monitoring systems. Its implementation is possible only if the corresponding accuracy and sampling rate are obtained for registration and processing of analog parameters. To this end, the following basic rules of metrology must be strictly observed:

1) the sampling rate of the observed parameter $._{par}$ must be at least $2/\ _{\min par}$:

$$f_{par}\ \ 2\ \ /T_{\min par},$$

where $T_{\min \mathrm{par}}$ steam is the minimum time constant of dynamic (transient) processes in terms of the value of this parameter;

2) he parameters used to control the observance by the crew of the flight and operational restrictions of the aircraft and the rules for operating the aircraft systems in flight must have an accuracy not worse than the accuracy of the corresponding instruments and indicators in the cockpit, the information of which the crew is guided by when making certain decisions. It is best to use the same information as the crew when monitoring crew actions;

3) he accuracy of registration of parameters used to monitor the state of technical systems Δ_{pa} , should be no worse than half of the least significant bit in the value of the C limit imposed on this parameter.

Results and its discussion

In order to form lists of parameters for objective control of heavy and light helicopters, it is necessary to first divide them into groups in accordance with the above objectives of objective control.

The first group should include the parameters that determine the movement and angular position of the helicopter in space. This group is common for any type of helicopter. Table 1 shows a list of parameters of this group with the recommended ranges and registration accuracy, as well as the frequency of polling.

Table 1

List of parameters of the general group for a helicopter of any type with recommended ranges and registration accuracy, as well as survey frequencies

Parameter name	Sensor type	Measurement range	Registration accuracy is not worse	Polling frequency, Hz
1. Instrument speed	ASS	50 ... 450 km/h	0.5 km/h	4
2. Barometric altitude	ASS	500 ... 7000 m	0.5 m	4
3. Relati barometric altitude	ASS	500 ... 7000 m	0.5 m	4
4. Vertic	ASS	± 50 m / s	0.1 m / s	4

The second group includes the parameters of the power plant. Modern helicopters, both longitudinal and coaxial, have a power plant consisting of two aircraft jet engines and an auxiliary power unit. This group can also be considered common for light and heavy helicopters of any design.

The third group includes the parameters by which the transmission must be monitored, i.e., the state of the main gearbox, bevel gears (if any), the intermediate gearbox, the tail gearbox, the transmission shafts, the main rotor (s) and the tail rotor are monitored. The list of parameters included in this group depends on the design of the helicopter.

The fourth group of parameters is formed to control the parameters of the helicopter control system, including mechanical wiring, electric hydraulic drives, an automatic control system with its autopilot channels and damping channels, which serve to obtain high dynamic stability characteristics of the helicopter flight. It is clear that the control system of longitudinal helicopters with a tail rotor and coaxial helicopters differs significantly from each other.

The fifth group includes the parameters used to control the helicopter power supply system. This system for helicopter-type aircraft has a typical structure, which provides for the presence of DC and / or AC generators as primary sources of electricity. The generators are driven by the helicopter main gearbox. The emergency power supply is as follows usually two rechargeable batteries. In the case of using alternating current generators as a primary source of electricity, the supply of direct current to consumers is carried out from rectifier devices (RD). To provide power to certain consumers with three-phase alternating current with a voltage of 36 V and a frequency of 400 Hz, special converters are installed on the helicopter. In order to supply consumers with a single-phase alternating current with a voltage of 115 V and a frequency of 400 Hz with the motors turned off, a special converter is installed. The power supply network of a helicopter, as a rule, is divided into three groups: a power supply group for consumers on the left side, a power supply group for consumers, an emergency power supply group for consumers. Based on the general structure of the formation of the power supply system for helicopters.

The sixth group is formed by the parameters that determine the control of the state of the helicopter hydraulic system. The design of the hydraulic system for most helicopters is standard, consisting of the main and backup hydraulic systems with their own hydraulic pumps. The main difference from the standard design can only be for helicopters with retractable landing gear and heavy helicopters. In this case, the processes of releasing and retracting landing gear or opening cargo doors (for heavy helicopters) is provided by its own auxiliary hydraulic system. To control the state of the hydraulic system, as a rule, measurements of two parameters are used: pressure and temperature of the working fluid, although to solve the problem of the consumption of hydraulic fluid, it is necessary to know the magnitude and speed of movement of the working rods of hydraulic machines (boosters), the frequency of rotation of the output shafts of hydraulic motors.

The seventh group includes the parameters of the fuel system, on the basis of which it is possible to estimate the total fuel supply on the helicopter, the remaining fuel in a particular tank. In addition, on the basis of the data on the remainder and mass characteristics of the loads placed on it, the on-board computer estimates the current mass of the helicopter, information about which is also submitted for registration. For helicopters capable of carrying cargo on an external sling, the mass of this cargo can be estimated and recorded.

The eighth group includes the parameters characterizing the operation of the air conditioning and oxygen systems.

The ninth group of parameters relates to the control of the helicopter anti-icing system. To a greater extent, this applies to the electric heating system of the main rotor or propellers and tail rotor.

The final – tenth group includes control parameters of the helicopter pneumatic system, which is used for braking the landing gear wheels, sealing doors and flaps, and pressurizing the tanks of the hydraulic system.

Additional sensors are designed to solve the problem of vibration diagnostics of critical mechanical components of helicopters - the main gearbox, angular, intermediate and tail gearboxes, as well as transmission shafts. For a more detailed diagnosis of the vibration state of the main gearbox, it is envisaged to install additional vibration acceleration sensors of the MV-45E type with one axis of sensitivity at each critical node:

– in the area of input shafts driven by free turbines of the respective engines;

– in the area of the shafts driving the main rotor (or propellers for coaxial helicopters) and the tail transmission;

– in the drive zone of the helicopter's vital units: hydraulic pumps, electric generators, and a fan.

Based on the readings of all sensors for determining the technical state, a multidimensional state vector of the AS is formed. In this case, a multidimensional border should be formed Gr_S separating serviceable Cr_1 and faulty Cr_2 state of AS, as shown in Figure 4.

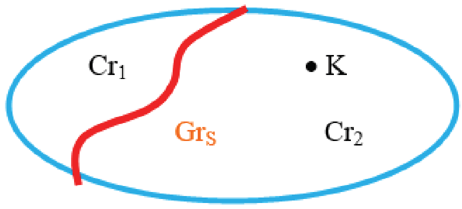

Fig. 4. The boundary dividing the serviceable and faulty state of the AS (K – multidimensional state of system malfunction at a specific point in time)

In general, you can take the set states of the monitored system metric. Then the border Gr_S will be described by the hypersurface $Gr_S = f(r_1^1, r_1^2 \cdots r_1^n, r_2^1, r_2^2 \cdots r_2^n)$... The task of diagnosing AS is such a description of system malfunctions (point K) that would meet the criterion described by the expression:

$$\min_{Cr_2} \|K - Gr_S\|_{\mathfrak{R}}$$

In other words, to solve the problems of diagnosing system S, such a structure should be chosen to describe its faulty states from the set Cr_2, which would be the closest to the border separating the serviceable and faulty states of this system [1, 2].

In addition, for helicopters with a tail rotor, for the purpose of diagnostic monitoring of the tail shaft, it is planned to install combined sensors of the MV-45TE type, which measure vibration acceleration and temperature at the sensor installation site. The sensors should be installed close to the bearings of each of the transmission tail shaft bearings. Measurements from such combined sensors will make it possible to perform point, joint vibration and thermal diagnostics of the condition of the transmission tail shaft.

The carried out patent research and analysis of the analogs of predictive and diagnostic systems available on the market showed that all available systems consist of two parts: ground and airborne. The onboard part includes the following functions:

– p ocessing of incoming information about monitored parameters from on-board registration devices and sensors;

– bringing it to a single form;

– control over the observance of flight technical restrictions;

– f rmation of a database.

The ground part performs the following functions:

– reading information from the onboard part;

– analysis of the knowledge base;

– ormation of objective conclusions about the technical condition of the aircraft;

– ormation of prognostic hypotheses and recommendations for the maintenance of aircraft;

– setting up the onboard part of the diagnostic system, managing the knowledge base.

Implementation of parallelism at the level of processor cores is the cheapest and most technologically advanced option with minimal restrictions on board sizes. If the board sizes are limited by the standard design (3U, 6U, etc.), this implementation of parallelism may not be possible.

The information model of such a system is shown in Figure 5.

The current development trend is the increase in the computing power of the onboard unit and the transfer (often duplication) to it of the maximum part of the functions of the ground unit in order to increase the efficiency of drawing conclusions and making decisions [16-18].

When monitoring the state of the helicopter's vital systems, including critical mechanical units, a trend and predictive control module should be used in the software of the ground complex, which performs two types of trend analysis: short-term and long-term. Short-term trend and predictive control is performed based on a time series

$$\Delta P_{\ con}(t_1),\ \ P_{\ con}(t_2), \dots , \Delta P_{\ con}(t_N),$$

where $\Delta P_{\ con}$ – the difference between the current and the reference value of a controlled parameter or a group (vector) of parameters characterizing the state of the system (unit) at time ti in the current flight when the system (unit) enters the j-th controlled mode.

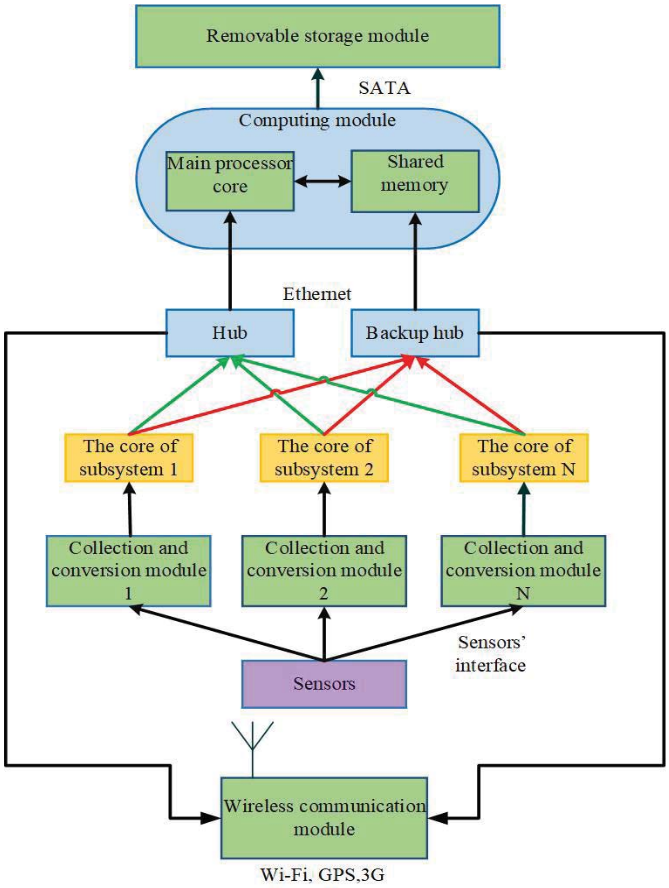

Fig. 5. A variant of the organization of the information model of the parallel system of prognostics and diagnostics

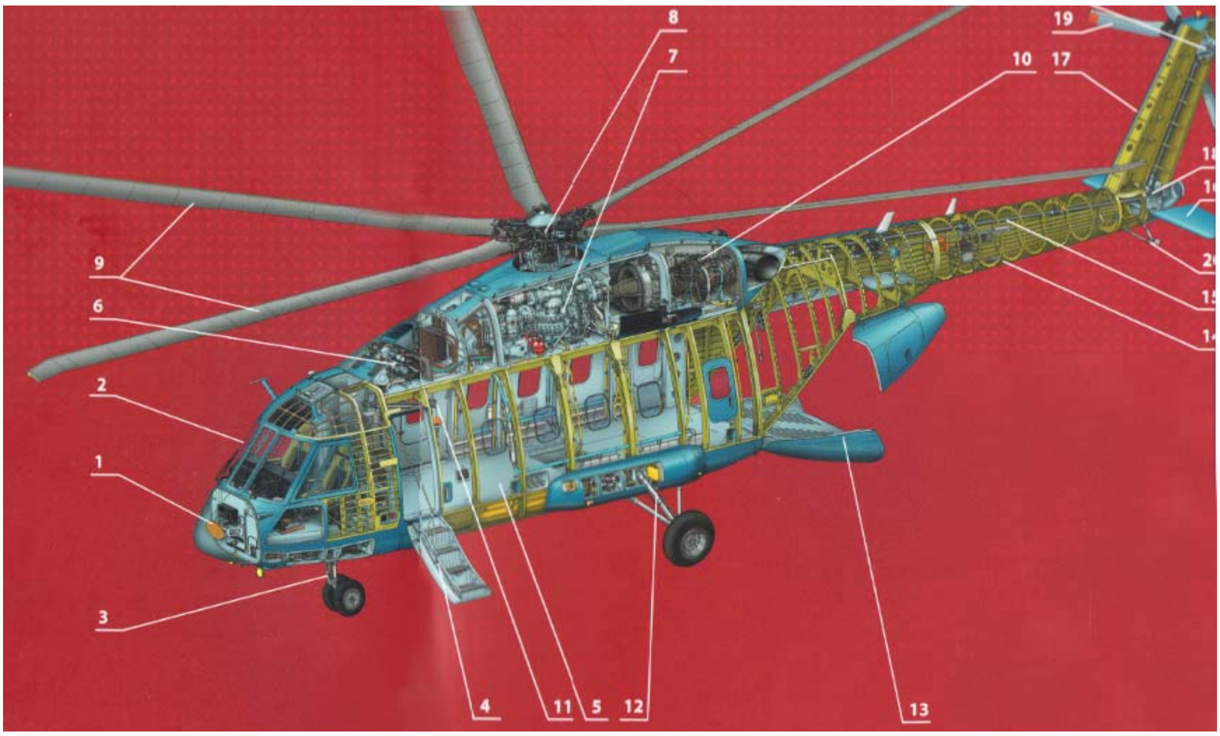

Fig. 6. Prospective scheme for monitoring the technical condition of the helicopter: 1, 3, 4, 11, 13, 17 – fiber-optic airframe deformation sensors; 2 – a module for transmitting all flight information to processing points in an aerodrome; 5 – module for monitoring the psychophysical state of the pilot; 6 – module for transmitting flight information via the SCS; 7, 8 – transmission monitoring sensors; 9 – rotor blades; 10 – engine monitoring sensors; 12 – airframe and chassis monitoring module; 14 – transmission monitoring module; 15 – emergency storage of information; 16 – module for transmitting information about the pre-emergency state; 19 – tail rotor

Long-term trend and predictive control is performed based on a time series

$$\bar{\Delta}P_{con}(T_{op1}, \bar{\Delta}P_{con}(T_{op2}, \ldots, \bar{\Delta}P_{con}(T_{.} \quad),$$

where $\bar{\Delta}P_{con}$ – average change in the state parameter of the system (unit) in the j-th mode in the i-th flight; T_{op} - operating time of the system (unit) in the j-th mode in the i-th flight; $T_{op.}$ is the operating time of the unit in the j-th mode in the current flight.

In this case, as an assessment of the danger of changing the state of the controlled system (unit) as a whole, the mode with the most significant trend and the worst forecast is selected.

The mode uses learning knowledge bases based on neural network technologies. In cases where this module is not capable of automatically making a decision on the current state of the monitored system (unit) according to the built-in logic, the system of interactive dialogue with the operator (decision-maker) is connected. At the same time, access is opened to the expert-reference system, which contains a database and knowledge, both for the operation of a specific vital system (unit), and for the entire fleet of systems in the operating organization.

Conclusion

Based on the study, the following conclusions can be drawn:

1) the choice of the nomenclature of the controlled units of the helicopter is determined by their purpose, the severity of the consequences in case of failure, testability (physical principles of operation, design features), conditions and modes of operation, the predicted level of reliability, as well as the experience of operating prototypes and analogues.

2) according to the degree of responsibility for the safety of the flight, all units and parts of the helicopter are divided into four groups.

3) the composition of sensors for diagnostic monitoring of helicopter assemblies and assemblies is determined after analyzing the necessary and sufficient parameters for real-time monitoring of the main groups and assemblies of the helicopter.

4) the range of measurements of specific physical quantities is assigned at the design stage of the corresponding control object (vital helicopter system). The upper and lower limits of measurement should be checked during preliminary and state tests.

The design stages of a diagnostic and predictive system should include simulation and semi-natural modeling. Based on the results of semi-natural modeling, the characteristics and control algorithms are refined. The parallel structure of the systems for diagnostics and prognostics of the technical condition of aircraft makes it possible to increase the efficiency of decision-making on possible failures and malfunctions by transferring a larger number of diagnostic procedures to devices and systems for on-board use.

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ИНФОРМАЦИОННАЯ МОДЕЛЬ ПАРАЛЛЕЛЬНОЙ СИСТЕМЫ ДИАГНОСТИКИ И ПРОГНОСТИКИ ТЕХНИЧЕСКОГО СОСТОЯНИЯ ЛЕТАТЕЛЬНЫХ АППАРАТОВ

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Аннотация
На сегодняшний день существует противоречие между постоянно растущей потребностью повышения степени функциональной насыщенности средств диагностики и прогнозирования текущего состояния летательных аппаратов и ограниченными техническими возможностями средств диагностики. Отмеченное противоречие постоянно обостряется вследствие постоянно повышающейся сложности летательных аппаратов и средств их автоматизации, что требует соответствующего увеличения функциональных возможностей средств контроля технического состояния. Всё это приводит к неоправданному увеличению массогабаритных показателей диагностических средств, что существенно отражается технико-экономических показателях при эксплуатации летательных аппаратов. В данной статье предложена информационная модель параллельной системы диагностики и прогностики технического состояния летательных аппаратов на примере вертолетов, охарактеризованы группы датчиков, входящие в систему, а также изложены принципы решение задач диагностирования и прогностирования состояния отказа авиационного комплекса. Предложена процедура накопления полетных данных о параметрах ответственных узлов и агрегатов на борту вертолета и метод экспресс-анализа, заключающийся в контроле в реальном масштабе времени за трендом параметров и скоростью изменения этого тренда к предельным значениям. Доказано, что должна быть предусмотрена выдача аварийной визуальной и звуковой индикации экипажу вертолета о нештатной ситуации.

Ключевые слова: *авиационный комплекс, вертолёт, система диагностики и прогностики, параметрический синтез, вибродатчик, полунатурное моделирование.*

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