Paper 169

NEW DIAGNOSTIC TECHNIQUES FOR ADVANCED ROTORCRAFT MONITORING SYSTEM

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Absracts

The article represents the review of the advanced rotorcraft monitoring and service system planned to be developed by Russian Helicopters. It considers the conversion to the condition based maintenance and capabilities of existing HUMS. The article states the objectives, tasks, and main functions of the advanced rotorcraft service system based on the helicopter technical condition monitoring. It presents the future system structure incorporating three levels as: airborne system, operator's ground station, and service and monitoring control centre using the manufacture's common database. It also describes the basic requirements applied to the advanced system in the part of service and monitoring. Feasibility of the requirements to advanced monitoring system in terms of vibration diagnostic techniques is analyzed. Monitoring of gas-turbine engine units and diagnostics of the specified failure of the planetary gearbox examined with new vibration diagnostic techniques are exemplified. It indicates the most advanced methods of inspection of the power plant units and fuselage components. The relevant summaries for the system prospects and capabilities of it promotion with Russian Helicopters Holding are made.

1. Introduction

The primary stage of Health and Usage Monitoring System (HUMS) application for helicopters was promising because it contributed to significant reduction of air accidents caused by transmission. However, the operators' expectations that such systems use will support conversion from the traditional maintenance techniques to condition based maintenance failed to be met [1]. The matter is that the operating systems were designed to provide higher flight safety and their purpose was to prevent air accident by generating dangerous defect alert. These tasks were solved by automation of well-known and properly worked-out techniques of flight mode and power plant (PP) operation monitoring. Particularly, to monitor PP, the overall levels of engine vibration or first rotor harmonics and vibration parameters of transmission and gear systems are used. The operating systems, can be said, are coping with the task of helicopters *service life* recording, however, their capacities are not enough for *health* monitoring. It is exactly that thing which determines low level of operators' trust in HUMS diagnostic capacities related to engines, main gearbox, shaft bearings, main rotor head and tail rotor hub and other PP units, as well as fuselage structure. Thus condition based maintenance that could provide higher efficiency of aircrafts, less operational costs as well as improvement of the flight safety is hampered by lack of reliable diagnostic and monitoring techniques. To build high-efficiency system, firstly, we need technologies that are capable of timely reporting about the incipient defects and preventing great number of the false responses that are inherent to currently operating systems. Secondly, we need organizational, financial, and technical capacities to integrate efforts of numerous organizations and companies in the field of research, development and promotion of such system.

2. Objectives, tasks and functions of the advanced condition based maintenance operation system

Russian Helicopters JSC has the potential for establishment of joint monitoring and service system required for condition based maintenance operation of its rotorcrafts. Russian Helicopters Holding incorporates many entities that provide design, manufacturing, service, and repair of the rotorcrafts and its assemblies, gearboxes, rotor heads and hubs, and blades thereof. Besides, the manufacturer of engines, which are installed in the Holding's helicopters, is incorporated in the same corporation, so the advantages of such highly integrated structure as the platform for constructing of the advanced monitoring and service system become evident.

The advanced maintenance/service system based on the monitoring of all vital PP assemblies and structure units is the basis for the helicopter condition based maintenance operation (monitoring-based service shall be abbreviated later as MBS). The monitoring shall cover the total helicopter life-cycle including acceptance tests, operation, maintenance, and finally, disposal. As for the maintenance, the functions of service quality control shall be imposed on the system in order to prevent the faults and potential installation of the counterfeited assemblies and units as well as undoubtedly inoperable assemblies. The establishment of such system, regardless of being complicated scientific and large-scale technical problem, can be implemented gradually within the reasonable periods of time. The promotion of similar system depends on successful solution of problems that are of the interests of operators, manufacturers, and overhaul facilities altogether. For example, the system must answer such an operator's questions like: *Is the specified assembly operating properly? How far has its operating performance deteriorated and is the assembly feasible to be operated further? What is the operating life remainder? Is the maintenance or repair required? Is the on-site maintenance feasible?* If the system will be capable to answer such questions, contributing by that to the operator's costs reduction and higher flight safety, then the operator will be interested in it. The system shall provide the manufacturer or the repair and service facility with the data required for higher production efficiency and product quality. These data will contribute to the non-productive costs reduction of the industry and will increase intellectual technologies share of the services to be rendered to an operator.

The following items are emphasized as the key MBS objectives :

- Higher flight safety;
- Reduced number of maintenance operations;
- Reduction of the ground checks;
- Prompt detection, review, and troubleshooting;
- Higher quality of the manufactured products;
- Operational costs reduced by means of operating life control.

The joint monitoring and service system framework offer opportunities for achieving goals in industrial and operational application such as:

- Technical condition monitoring of the individual rotorcraft's assemblies and units; and
- Monitoring of the rotorcraft operating system efficiency in order to ensure flight safety and rotorcraft fleet operating life control;
- Interpretation and release of the monitoring results in the way of recommendations and instructions to the pilot, operator, manufacturer and maintenance and repair organizations (MRO);
- Monitoring of rotorcraft assemblies and units shifting in the operating process;
- Monitoring of the soundness and regularity of the rotorcraft service;
- multilateral exchange, storage and processing of the monitoring results and assemblies shifting.

Whilst carrying out the above tasks, the system will provide the operator with the manufacturer's feedback including claims processing, fight against the counterfeited parts and unsound maintenance, air accident investigation, etc.

3. Vision of the advanced system

What are the differences between the advanced system and the existing ones? Firstly, MBS will incorporate both the functions of the monitoring and diagnostic system and common service system. It is required because the conversion from planned and preventive technique to the condition based maintenance operation cannot be provided without relevant manufacturer's supervision. Secondly, the level of MBS diagnostic potential will allow rise from monitoring the trends of parameters of some assemblies towards the ultimate control over the technical condition of the whole rotorcraft. Jointly, these differences will provide not only higher safety, but economic efficiency of the helicopter as well.

Besides the airborne system, data accumulation, temporary storage/communication means, and ground station, the advanced system will also incorporate the manufacturer's integrated information centre. Here's an example given below describing the structure of such system operating on three levels.

Level 1.Airborne System

The system starts running from the rotorcraft side where two main tasks are resolved: 1) prevention of the catastrophic development of the defect; and 2) data primary processing and accumulation for subsequent analysis on the ground. To provide such functions, the system include sensors, units for signals conditioning, data processing and storage and crew audio alerting and visualization systems. The sensor layout pattern for particular helicopter type is shown on Fig.1. Gradual development of the system is assumed; hence, the set of the signals from the sensors mounted in the helicopter is determined by the flight safety requirements and current technology level and economic feasibility.

The intellectual level of the airborne station shall provide the detection of the most hazardous defects during the flight with regards to the influence of the flight conditions. For this purpose, the airborne system will control the parameters including:

- Compressor, turbine, main rotor, and tail rotor RPM;
- Oil chips indication in the main gearbox, transmission, and engine;
- Temperature and pressure of engines, main gearbox, transmission, and hydraulic system;
- Engine and main rotor torque,
- Ambient air and turbine gas temperature,
- Service life usage of the engine and the auxiliary power unit (APU) and number of APU starts;
- Total number of landings including bungled landings;
- External navigation information (GPS, GLONASS);
- Indicated airspeed;
- Barometric and radio altitude,
- Rate of hovering turn and rate of descent;
- Bank and pitch angles;
- External suspension load,
- (Right or left) pedal travel;
- Overload (- and +);

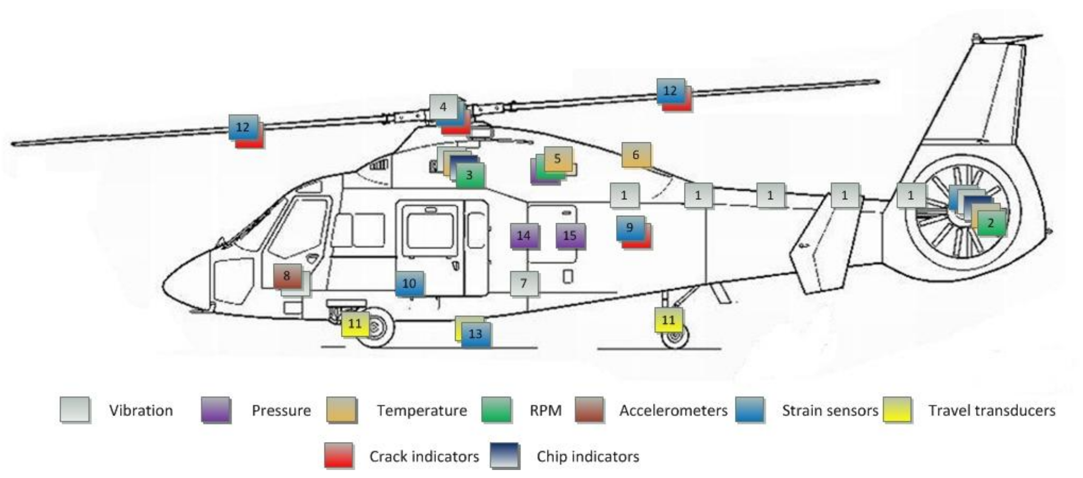


Figure 1. MBS rotorcraft sensor layout pattern:
1.Transmission shaft bearing supports; 2.Tail rotor and gearbox; 3.Main gearbox; 4.Main rotor head; 5.Engine; 6.Engine exhaust system; 7. Fuel pumps; 8. Fuselage; 9. Tail rotor pylon; 10. Strain members of the center fuselage section; 11.Chassis; 12.Blade; 13. External sling; 14. Chip indicator; 15.Fuel system; 16. Oiling system.

- Vibration of the main rotor, tail rotor, engine, main gearbox and tail gearbox, shaft support bearings, fuel and oil pumps, electric motors and generators;
- Signals of strain gauges and acoustic emission on main rotor head and tail rotor hub, blade , strain members of the fuselage, and tail rotor pylon substructure;
- Integrated cracking indicators at rotor hub units, blade , and tail rotor pylon fixture points.

Airborne station shall unambiguously alert the pilot about the systems' status, for example READY FOR FLIGHT or MAINTENANCE REQUIRED or FLIGHT IMPOSSIBLE.

Airborne station will exchange the data with electronic passports (EP) of the assemblies and units in order to supervise the item during the operation. The EP will contain the updated set of item's data saved at the integrated storage device . The information recorded in the EP is also saved in the ground station of the operator and overhaul facility and the manufacturer's central database. The EP will incorporate the typical set of data including identification numbers, dates, service life, etc.

The information contained in the EP shall be updated regularly during the operation, and whilst maintenance, this information will be transferred to the operator's ground station and manufacturer's integrated information centre. The replacement of any assembly of the helicopter shall be recorded in the EP of such assembly and helicopter automatically.

Level 2. Ground Station

The information accumulated during the flight will be transferred to the operator's ground station via:

- Laptop with the service interface providing the prompt on-site evaluation of the systems, for example, at the remote sites;
- radio link (Wi-Fi) providing the data communication to the ground station;
- Flash memory medium.

The obtained information is automatically interpreted at the operator level and/or by the manufacturer's integrated information centre from where information is transferred back in a way of maintenance or repair instructions. Based on the processing results, the technical condition forecasts are made and service life of the assemblies of a single helicopter, operator's fleet and the overall fleet of helicopters is planned.

By using the ground station, the operator monitors the fleet of own helicopters, plans repairs and services and controls the management of the operation documents. This ground station provides the tracking of the changes in Maintenance Guide (MG) the e-format of which is updated automatically by the manufacturer's integrated information centre. Ground station provides the accounting of the parts and units, elaborates, and makes the amendments to the item's EP.

When failure or defect is detected, the ground station enables the operator/repair and service facility to fill in the EP claim report by which the system will send the failure notification to the manufacturer. The failure details are recorded in the integrated information centre by which it is decided on the guarantee repair and relevant specialists to be sent.

The information available in EP of the assemblies, units, and the whole helicopter are transferred to the ground station database too. The Level 2 notifies the operator automatically about the necessity of the repair works and required service basing on the observed service life. The operator is also automatically informed about the recall actions made by manufacturer and receives the bulletins.

The ground station software shall also ensure the incipient failure reports to be generated manually and automatically and the relevant data transmitting to manufacturer. Similarly, the operations shall be conducted at the ground station of the repair and service facility that will require the customized format of Level 2 providing data transmitting both from rotorcraft and common database.

Level 3. Manufacturer

Level 3 is presented by service and monitoring control centre that uses the manufacturer's common database (MDB). It contains the information on all rotorcrafts manufactured including configuration and the list of maintenance and repair operations provided by the operator, MRO, and manufacturer. Claims, guarantee repair requests are entered into MDB where the fleet-related data are generalized as well. When the relevant amendments are made to MG and Flight Manual, the necessary documents and bulletins are distributed automatically among the operators. MDB communication with other parts of the system is shown in Fig.2.

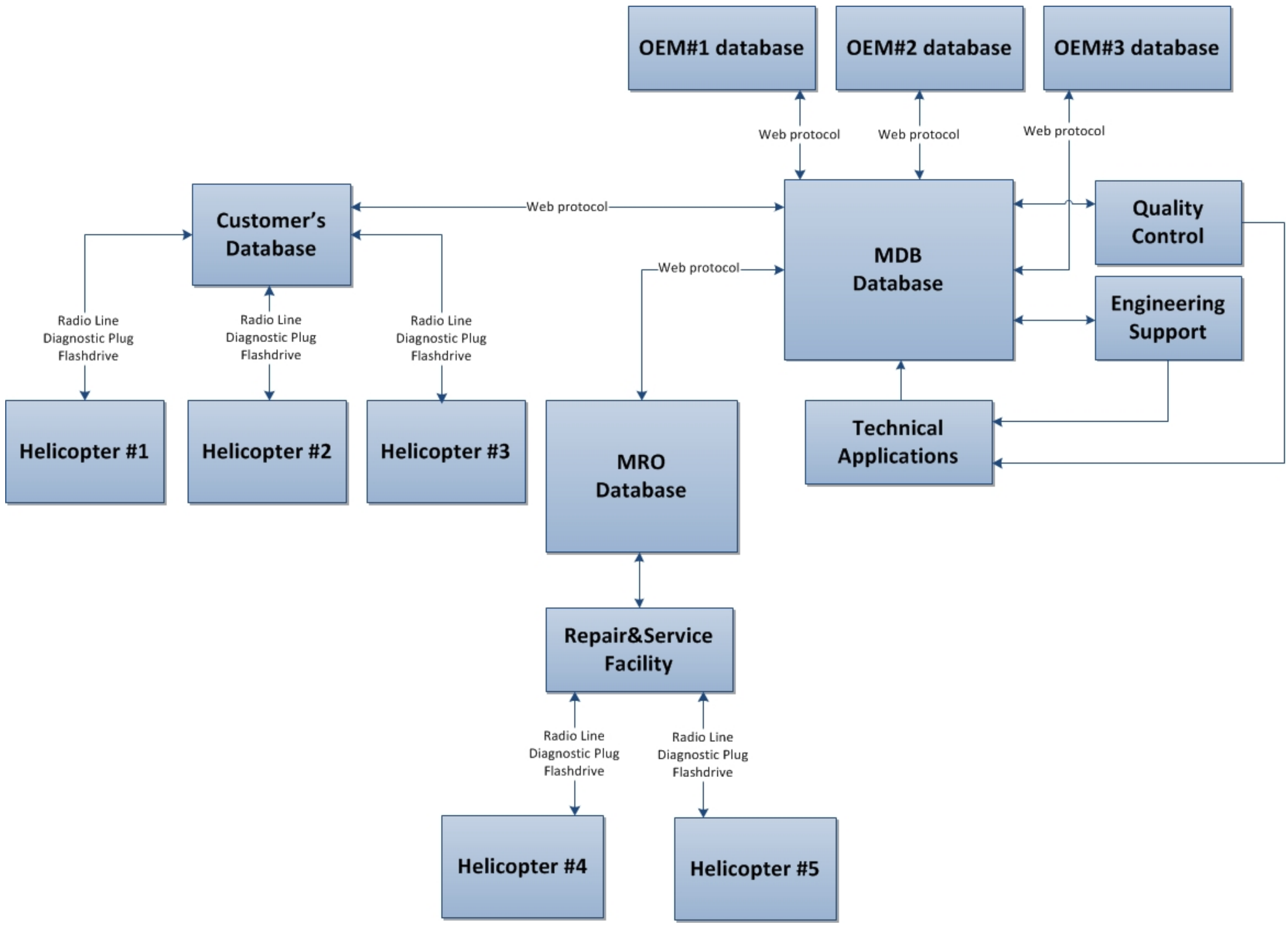


Figure 2. System's communication pattern

The monitoring results obtained from the rotorcraft airborne systems will be accumulated, processed, and stored on MDB servers. Based on the results of processing and according to the area of manufacturer's responsibility, the ready-made decisions will be forwarded to the operator. By using MDB, the manufacturer and the operator can track the history of rotorcraft units operation throughout the whole operating life.

MBS will provide the rotorcraft to be included to the common information space that integrates the manufacturer and MRO with the operator. In maintenance, the system as the automatic claim processing tool will provide the simplification of the typical failures detection and, consequently, contribute to higher quality of the products manufactured. MDB will provide the generation of the compatible databases for component manufacturers (components of rotorcraft, engine, blades, gearboxes, transmission, etc.)and MRO. The system will provide the elimination of unauthorized use of the assemblies of expired service life and service duration. In monitoring, the system will provide the concentration of the status data of rotorcraft assemblies and units in the manufacturer's common database from one hand, and the operator's database data to be continuously updated by the information consolidated throughout the overall fleet.

Data will be transmitted on-line via Internet or other information networks as, for example, in [2]. The global vision of the system and elaboration of technical and other requirements to the system's separate parts will be required for solution of this problem.

4. MBS requirements

In service, MBS is intended for optimization of service operations and repairs by those works only that rotorcraft's actual condition demands. The system should be enabled in every service stage and provide:

- The automated generation of the technical maintenance documentation;
- The automated supervision of maintenance operations;
- Rotorcraft assemblies and units shifting;
- Automated accounting of the claims and MG updates.

General requirements to the system in terms of *monitoring* focus on the advanced rotorcraft monitoring techniques that shall provide the automatic decision delivery with the minimal involvement of the high-skilled specialists. However, twenty-year experience of HUMS operation has detected plenty of problems related to monitoring application. From one hand, vibration parameters were admitted to be the most efficient in monitoring of some assemblies, like shaft support bearings. From other hand, the experience evidenced the insufficiency of the traditional approaches to provide reliable monitoring of the more complicated PP assemblies, especially, engine. The attempts to monitor the assemblies of the rotorcraft engine by techniques, worked out in the industry before, often cause the false responses or defect skips. This is the situation, for instance, with the monitoring of engine bearings and gear systems based on their vibration parameters. The gas air flow duct of the engine is not monitored in the helicopter at all; although such defects are often the reasons for early dismantle of the engines and related economic losses. Although the state-of-art data processing techniques are more and more used in the operating HUMS, including neural networks; however, they have to deal with the out-of-date engine vibration modeling. Meanwhile, the efficient logic of the systems has to use magnitude of vibration spectrum components of limited information value that represent the outcome of the nonlinear fuselage reaction to the nonlinear interaction of the running parts of the engine. As a result, HUMS efficiency in vibration diagnostics of the engine and some other PP assemblies turns out to be low.

New monitoring systems have to provide reliable monitoring of the engine, gearbox, and other PP assemblies in terms of vibration and other operating parameters, as well as automation, and higher objectiveness of the decisions made versus the monitoring results. Vibration diagnostic techniques required for such systems shall be based on more advanced integrated models of the exciting loads generation and the response of the vibration sensors mounted on the casing. These techniques shall regard the multiplicity of the exciting force sources and influence of the operation factors upon these sources, nonlinear nature of correlated and non-correlated excitation sources interaction as well as nonlinear response to the excitation of assembly housings. The trustworthy models of vibration components generation that have diagnostic value shall be the outcome of such approaches. It also provides that the physical bonds between interacting parts and vibration signals recorded shall remain the core in such models. As a result, the better the interactions in the operating assembly will be accounted by the model, the more reliable the diagnostic properties will be extracted. Figuratively speaking, such approach shall provide the transition from operating unit's vibration 'signature' to its vibration 'passport' that characterizes the operation of the interacting parts in details.

To implement such advanced approaches, more advanced measurement and vibration analysis equipment will be required to be used in a rotorcraft including:

- Operation's measurement range (minimum by 50kHz) and temperature range extension;
- Development of new dynamic signal processing techniques including frequency-time processing;
- Development of decision-making approaches;
- New technical and software solutions intended for technical and economic optimization of the airborne and ground operations.

Apart from the vibration monitoring, other techniques should also be developed including:

- Operation efficiency monitoring against the thermal, gas, and dynamic parameters;
- Monitoring of the members of rotorcraft fuselage against the strain and acoustic emission parameters;
- 'Smart' materials (the Lamb waves) and modal analysis techniques;

and diagnostic troubleshooting against the above parameters combined.

5. Monitoring requirements applicability

It should be emphasized that the majority of the above requirements to the new monitoring and diagnostic techniques are set by virtue of the current research and development works including those with the author involved. Some research works have already been implemented experimentally or empirically. The full-scope of the problems to be resolved by and set to the advanced system will certainly require the scientific research including theoretical analysis, lab and stand experiments, as well as flight and field tests and trials. The researches are planned to be conducted under own programs and joint research programs.

The prospects of the successful resolution of the rotorcraft monitoring problems are instantiated by new techniques of different progress status. The rotorcraft assemblies and units which monitoring is still problematic in operation have been specifically stressed.

Engine

The state-of-art turboshaft engine is the most complicated and expensive assembly of the rotorcraft. The engine monitoring to prevent failures is the essential to the safety to be ensured, and the transition to condition based maintenance of the engine is one of key sources of the reduced costs related to helicopter operation. Until now, the helicopter engine monitoring has been limited by the rotor vibration to be monitored at their rotation frequency, and in some advanced HUMS, the attempts of monitoring of the bearings and gear systems of the engine drives are made. As it was mentioned before, such monitoring could not gain operator's confidence.

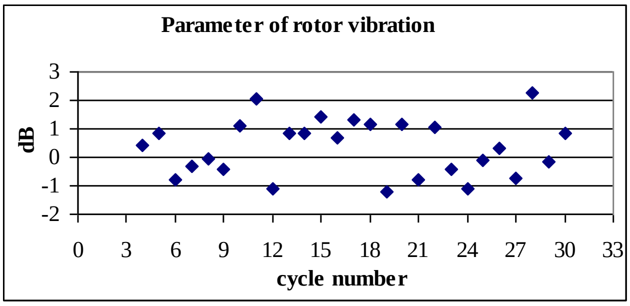
With regards to the new approaches, there's been developed the experimental system of the helicopter engine vibration monitoring that passed the tests at the manufacturer's stands followed by the experimental operation by the air company under the checks of the engines during the maintenance [3]. *Technically*, this system differs from the existing ones by the extended ranges as dynamic range (160 dB) and frequency range (0...25 kHz), as well as three-axis accelerometers mounted on the compressor and turbine. Two matters of principle distinguish the *intellectual* part of the system from the analogues.

The first matter is associated with the approach to evaluation in engine assemblies' condition modification in pursuance of the vibration passport principle (VP). *Typical* VP (i.e. specific to the type of engine) incorporates few hundreds of vibration parameters (primary condition indicators – *PCI*), each being related with the operation of specific part of engine by the physical model. To monitor the separate engine's assembly, one or more aggregate parameters are used, and each one is combined of several PCIs (from single PCI up to tens PCIs). The methodology of the usage of the typical VP for the specified engine means the monitoring of the modification of every aggregate parameter versus the original value of this parameter. Thus, the *individual* VP indicates the modification of the current vibration condition of the engine versus its original condition. The values of PCI and aggregate parameters of the specified engine are computed based on the measurements within the fixed range of the engine's operating modes. Such combination of measurements can be achieved during the testing of engine to be carried after the ground check or at different rotorcraft flight phases. The values of the aggregate parameters of every engine are normalized to the values measured at the beginning of their life; therefore, the allowed and emergency parameter limits are possible to be set as uniform to the overall fleet of the helicopter type. These limits are determined against the results of the researches and tests related to the failure statistics. So, the modification in the engine's technical condition is monitored against its individual vibration properties, and the proximity of such condition to the allowed and defect limits is monitored against the values obtained by the experience related to the fleet operating life.

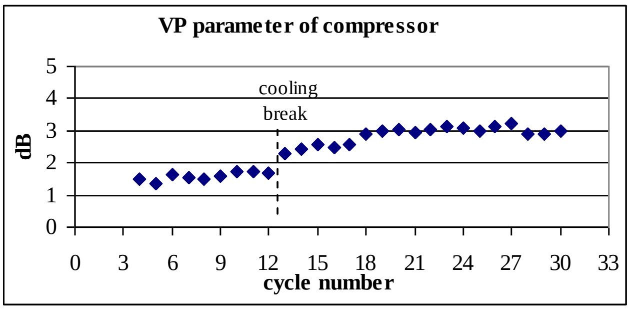
The second and main difference means the model of the complicated mechanism of gas turbine engine casing vibration that is generated by the multiple correlated and uncorrelated sources. If these sources' impact is considered adequately, then condition of every source can be evaluated by modification of its excitation that contributes to the casing vibration. VP techniques of the signal processing that are based on the casing vibration model allowed reduction of the structural and operation factors influence on the estimates of excitations. Due to VP techniques the estimates of excitation, which distinguishes the operation of the particular engine assembly, became more credible. From one hand, higher reliability of the aggregate parameters enables the individual vibration passport to indicate the actual condition modification of every engine. From the other hand, it provides to determine actual limits for all aggregate parameters based on uniform allowed and emergency limits, calculated to the overall fleet.

The trials of the system's operating capacity through the tests of the engines at the manufacturer's test stand and the experimental operation at the helicopter company showed the advantage of VP techniques over the traditional ones and prospects of on-board engine monitoring in field conditions.

Fig.3 shows the results of the test series of the turbo shaft engine at the manufacturer's test stand. This test involved 30 consequent cycles, where each cycle included the start-up, acceleration to maximum power and followed by the stop with the short cooling period after. When 12 start-ups were over, the long period of interruption was allowed to cool the engine.



a)



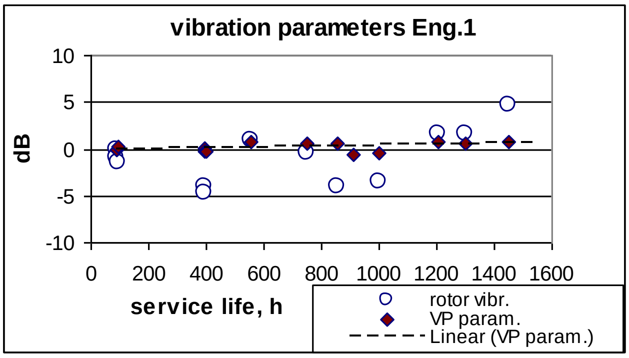
b)

Figure 3. Elevation of compressor vibration parameter to start-up number in a series of tests: a) – conventional rotor vibration parameter; b) – VP parameter that determines the compressor's air flow duct.

Before test series the engine has been overhauled and passed the acceptance test, hence, the condition modification during the series was associated with mechanical running-in of bearings, blade attachments, seals, and other contacting elements. The conventional parameter of rotor vibration (see Fig.3a) measured at the rotor speed varied chaotically with scatter exceeding 3 dB. Contrary, the values of the VP parameter, which monitors the condition of the compressor's air flow duct elements (see Fig.3b), were stable and indicated modification of compressor condition in running-in by 20^{th} start-up approximately, after which the VP parameter values got stable.

The rig tests have demonstrated the prospects of stable parameters to be achieved minimally scattered that allow monitoring the actual condition modification of the engine assemblies, even minor ones such as running in start of operation.

The operating conditions of the helicopter engines are remarkably different from rig test operation. The influence of external factors and operating mode significantly increases the variation of the engine operating including vibration. In such conditions, the advantages of VP monitoring techniques become more obvious. Fig. 4 compares the behavior of traditional and VP parameters against service life based on the results of the experimental operation of two engines in one helicopter throughout the total service life between repairs (1,500 hours).



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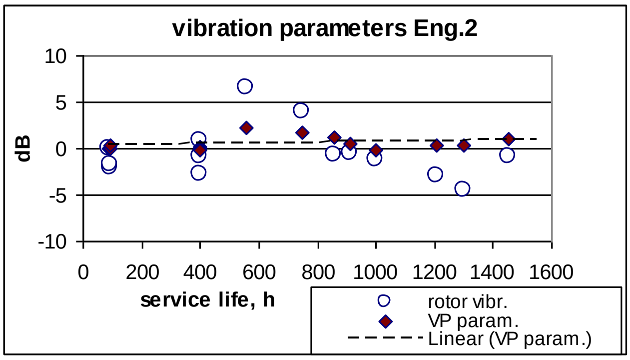

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Figure 4. Engine 1 (a) and engine 2 (b) vibration parameters behavior against service life: rotor vibration parameter values are indicated in circles and compressor air flow duct parameter – in rhombus.

The great variation of the conventional rotor vibration parameter does not allow any trend to be detected. Simultaneously, VP parameter of the compressor in both engines varied slightly as far as $\pm$0.6dB for Engine 1 and $\pm$1.2dB for Engine 2, and basically demonstrated the slight trend of 0.04 dB per 100 hours of service life, uniform to both engines. Trends simultaneity of VP parameters of both engines shows the equal rates of their compressors condition modification. Such simultaneity is determined by the fact that two engines operated in equal conditions under one PP, and apart from equal service life rates, these engines are equally impacted by erosive wear.

VP technique allows the engine and its compressor to be monitored both as a whole and by assemblies as shown by the examples below: VP parameter of compressor's 1^{st} stage, Engine 2, in the helicopter against operating life (Fig.5); and first support bearing load VP parameter (Fig. 6) of the engine tested on the test stand. The share of every such assembly in casing vibration measured by the sensor is remarkably smaller that the compressor's as a whole, therefore, the variation of VP parameter values of small assemblies is rather greater.

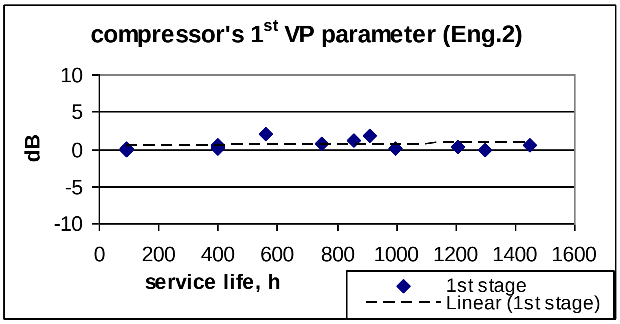


Figure 5. Compressor's 1^{st} stage VP parameter values against service life (Engine 2)

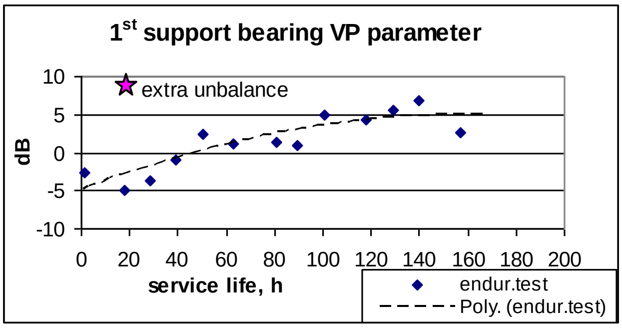


Figure 6. 1^{st} support bearing VP parameter against service life (Compressor, Support 1)

However, the trends demonstrated by the mentioned parameters remain adequate to the compressor at whole and conforms to test defect impact. Thus, the behavior of VP parameter of compressor's first stage (Fig. 5) was similar to the behavior of the whole compressor.

VP parameter of 1^{st} support bearing (Fig. 6) shows the dynamic load to be influenced by both rotor unbalance and rolling surface properties. So, 10dB gain within first 100…120 hours followed by the stabilization has corresponded to the bearing running process. Almost the same gain (of 9 dB) of the parameter was caused by the extra imbalance of the compressor's first stage.

The given results show the real prospects of monitoring of the engine's assemblies in helicopter by using VP techniques providing the diagnostic parameters to be extracted from the vibration signal.

Gearbox

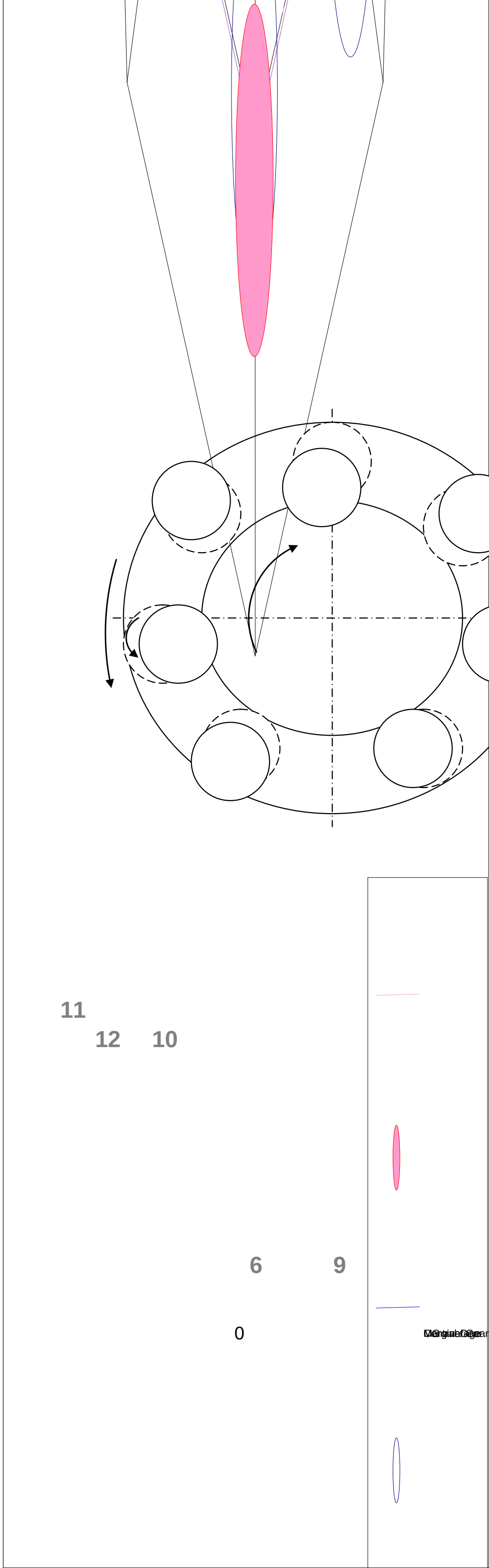
As the vibration monitoring object, the helicopter gearboxes are settled by HUMS designers better than the engines. The existing techniques allow the majority of gearbox vibration sources to be detected. However, the application of the existing techniques faces serious difficulties on the way of being implemented in the helicopter.

The most common problem is the elimination of the exposure of engines' operation and flight modes to the measured vibration parameters. The vibration parameters of gearbox sources may vary, for example, under impact of minor fluctuations of engine shaft rotation speed or ratio of such fluctuations in case of coupled engines. Even more influence can be imposed by helicopter maneuvers that cause the redistribution of the transferred energy in planetary gears. New techniques are required to be developed that will provide invariance of the diagnostic indicators for gears condition monitoring as it has already been developed for the engines within VP technology.

Another serious problem is the monitoring of planetary gears, in which two or more gear wheels have the same rotation speed. The monitoring of such gears is required due to irregular load distribution between operating gears. The teeth and bearings of the overloaded gear wheels may be wearing down more rapidly than other ones. Such gears diagnostics is feasible only by using the analysis in integrated time-frequency domain. To settle this problem completely, the gear engagement marker is required in the gearbox that would involve the amendments to the design and will cause further product appreciation. As for newly designed gearboxes, such problems can be solved; however, this is not a way-out to the existing gearboxes.

The problem of this type is settled by the specifically elaborated technique of frequency-time transformation of vibration data to be measured by two accelerometers that are mounted on gearbox in two orthogonal directions. Together with the vibration, the speed of gearbox output shaft is recorded by the tachometer. Fig.7 shows the lay-out with the examples of regular and irregular location of the planetary idle gears in the main gearbox.

In pursuance of the elaborated technique, the irregular dynamic effect is monitored by interaction of every gear wheel separately with the internal and external gear. Fig. 8 shows the prospects of the technique via radar diagrams by real examples of regular (Fig. 8a) and irregular (Fig. 8b) distribution of the dynamic impact between gears of two operating gearboxes. The impact values on every gear are determined by the distance between centre and a circle shown on the diagram: red (solid) circle employs internal gear engagement; blue (transparent) circle employs the external gear engagement. In regular distribution case, the external and internal engagement impacts differ lightly, and the impact values of both



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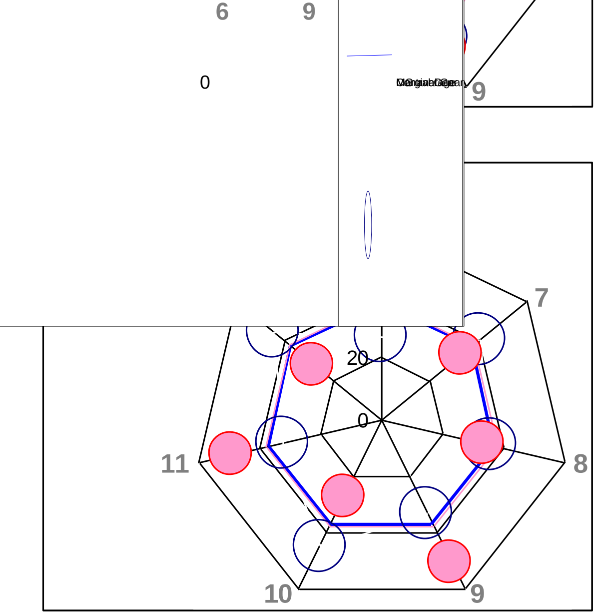

b)

Figure 8. (Radar) diagrams of gear impact distribution (g^2): a) – regular location of idle gears; b) – irregular location of idle gears.

As shown by the given example, new modern techniques provide more reliable and correct detection of both the defects themselves and even modification of operating conditions that may cause such defects.

PP assemblies

Vibration diagnostics can provide the majority of PP assemblies with the rotating parts to be effectively monitored. Monitoring techniques applied to the bearings of the transmission and gears are the most successful in HUMS by now. Vibration monitoring techniques are being improved proactively to be more interference resistant and to have reduced false responses and higher-reliability diagnosis and prognosis.

Among machines and mechanisms for which the existing or developed systems use vibration diagnostic techniques, we can distinguish electric motors, generators and converters, pumps and fans, hydraulic units, etc. However, most assemblies in helicopter are not monitored by now.

Some assemblies that are mounted on the engine housing rigidly can be monitored by engine's sensors. High resolution of VP technology allows such problems to be resolved by expanding the system capacities with no further costs of hardware.

Main rotor head and anti-torque rotor hub

The rotor head and hub monitoring still remains complicated technical problem. Up to now only vibration monitoring is actually used. Vibration is measured at the rotor head supports. The time-related variation of the head vibration signal provides both the monitoring of dynamic loads and obtaining of the data necessary for rotor balancing. However, these techniques fail to provide timely detection of incipient defects of the head or hub. The systems that provide the extra monitoring of the strains of head or hub elements by strain meters or acoustic emission signals [4] (caused by the strain waves associated with the crack or defect extension) are far promising. To make such head or hub as well as blade monitoring system more reliable, the wireless measurement data communication is proactively developed [5]. The experimental battery supply systems are manufactured, but the power self-supply systems are under active development now [6]. These systems use piezoelectric elements as the power sources that generate power by the loads applied to such elements.

Blades and fuselage sections

The use of the fast developed smart materials that can provide the blade, tail boom, and other elements to be monitored is the most promising. The basic principle to be laid in such systems is the monitoring of the Lamb wave propagation inside the material structure.

To provide prompt field monitoring of the blades and fuselage elements, the modal testing techniques at a ground check can appear to be advanced. Such technique allows, for example, the blade's structure or elasticity modification to be monitored by modification of the modal properties. This technique can be implemented at field by using the portable tool kit including a couple of accelerometers, and force sensor hammer. Using the technique specified for each type of blade, determining the blade testing route and automatic processing of the test results, the current modal properties of the blade could be calculated. Modal parameters comparison with the original ones attained at the blade installation in the helicopter will prove workability of the blade or will provide diagnostic message about the possible failure and feasible blade troubleshooting.

Further development of the monitoring techniques related to blade and fuselage components is envisaged in application of modal analysis techniques during the flight. The monitoring will be conducted by the embedded sensors and actuators that will be able to provide automatic monitoring by airborne system. Besides, the operating modal analysis techniques will allow monitoring components of the fuselage and blades during the flight when the aerodynamic or other interaction of helicopter will be taken as the test impact.

Summary

Based on the analysis of the current HUMS, it was summed up that such systems are insufficient for helicopter condition based maintenance operation. There have been elaborated the proposals for three-level configuration and overall structure of the advanced helicopter technical monitoring and service maintenance system that will be able to provide the condition based maintenance operation. Such system will meet the operator and manufacturer requirements. In the advanced system, the monitoring, first of all, will be based on the new vibration diagnostic techniques, engine performance monitoring, advanced techniques related to monitoring of main rotor head, anti-torque rotor hub, blades, and fuselage components. The prospects of built-in sensors and modal test techniques are distinguished for the monitoring of structures.

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