Unified advanced HUMS and maintenance system for “RH” helicopters

D. Podoryashy [1], *A. Soloviov* [1], *D. Soloviov* [1], *A. Mironov,* [2] *P. Doronkin,* [2]

[1]- Russian Helicopters CI&C, Russian Federation [2]- D un D centrs, Riga, Latvia
a.soloviov@rus-helicopters.com aleksei@ddcentrs.lv

Abstract

The article describes the project on development of Advanced Health and Usage Monitoring System (A-HUMS). A number of works carried out jointly with R&D centers within the scope of this project is outlined. Problems of furtherance of new monitoring systems are reviewed. Methods and experience of advanced technologies approbation on test benches of manufacturing plants and on helicopters in real conditions are illustrated.

1. New diagnostic technologies for Advanced-HUMS

The most of modern helicopters are equipped with systems collecting and processing flight and main units operating data. Aggregates’ parameters monitoring performed by such systems allows their individual operating time logging. However, the aggregates’ service life remains limited by threshold of operating time stated within frames of periodic maintenance system and not related to the actual state of the given aggregate. This system of operation cannot comply with increasing requirements to flight safety and economic efficiency of rotorcraft applications. Transition to condition based maintenance of helicopter and its aggregates will allow operational cost cutting reducing and increasing of products competitive abilities. Such system is acknowledged as the most effective from the economic point of view and will become a dominating tendency in the development of helicopter operation and maintenance. Therefore, requirements to flight safety, operational costs reduction and efficiency of helicopter application dictate the necessity to facilitate a rotorcraft by such HUMS that would allow the conversion to condition based maintenance.

Reduction of the cost of system’s development and the time for its adjustment to various types of rotorcraft is a mandatory requirement to A-HUMS. This harmonized scalable system with open architecture allows to meet the requirements to common quantity and quality-related monitoring tasks for various-class helicopters. The spectrum of monitoring system’s functions expands with the increase of payload, responsibility and risk relating to the undertaken mission, complexity of operating conditions and cost of the helicopter. Besides, A-HUMS is significantly affected by specific customer’s requirements defining its functionality. The modular structure of on-board A-HUMS unit and software will allow the system adjusting to any class of aircraft and to the customer’s requirements. Moreover, usage of common information processing algorithm and common database will allow to increase monitoring effectiveness considerably.

Establishment of a complex maintenance system based on monitoring is a staggered process requiring long-term efforts. For convenience we can highlight the following stages:

1. Helicopters equipping with the on-board system supported by the ground station. At this stage A-HUMS generates recommendations on certain helicopter aggregates, requiring additional checks and maintenance activities. Besides enhancing flight safety the benefit from system implementation at this stage comes from improvement of technical maintenance planning and rotorcraft application.

2. Introducing new requirements to aggregates' diagnostic depth and central database establishing. As the result of this stage, the data on the new rotorcraft fleet will be accumulated and the evaluation of technical and organizational solutions efficiency, embodied in the new helicopters and systems, will be achieved.
3. Further expanding of the aggregates and systems range to be monitored. Diagnostic depth increasing. Transition to comprehensive condition based maintenance along with decrease of scope of scheduled and unscheduled maintenance.

In order to implement A-HUMS the existing diagnostic techniques are being developed and the new ones are being created. On the basis of successful results of lab research and tests new diagnostic technologies such as monitoring of power plant aggregates and critical components of airframe structure are planned for testing and certification. As an example we can mention a deepening of diagnostics of engines, gearbox and transmission, new methods of monitoring of main and tail rotor hub components, as well as main and tail rotor blades, swash plate bearing. As the new technologies are being developed, HUMS functionality will be expanded with regard to the condition of certain aggregates monitoring due to software upgrade of HUMS ground stations and expansion of functions owing to upgrade of on-board components. The system of maintenance, repair and logistics will undergo improvement in order to gain benefit from on-condition maintenance of certain aggregates.

At present in the course of implementation of A-HUMS project ”Russian Helciopters” (RH) Holding has installed monitoring systems on existing Mi-8MTV1, Mi-171A helicopter types. Systems for Mi-171A2, Mi-8MTV5, Ka-62 and advanced helicopters are under development. Special attention is paid to new technologies development of signals processing. For a more dynamic development of diagnostic technologies RH team is cooperating with R&D centers. As a result of such cooperation the advanced unified monitoring system (A-HUMS) shall emerge. The system shall provide monitoring of all moving and rotating aggregates without exception, the majority of vital components and aggregates of fuselage structure and systems. Besides, high level ground support with the stations at operator's facilities and the central data base at manufacturer's facilities will be established providing conversion to individual technical condition maintenance of a helicopter and its aggregates.

II. New technologies' progression challenges

At present, there are diagnostic techniques, primarily based on vibration, and operating at a laboratory or on-ground testing phase, which are capable to provide monitoring and diagnostics of helicopter aggregates within their whole life cycle, allowing on-condition maintenance. However, there is a delay in developing of the methods and algorithms of helicopter's systems and structures diagnostics. The delay is caused by insufficient cooperation between helicopter designers and HUMS developers from one side, and R&D centers developing new diagnostic techniques, from other side. A helicopter designer cannot apply new technologies, if they have not passed *comprehensive tests and certification*, and more often assuming that designers of aggregates or the manufacture of HUMS should debug such technologies be performed by. The latter has not a possibility to be engaged in that, being a designer of airborne equipment, but not of diagnostic techniques. Designers of aggregates, if engaged in diagnostics, would solve only their own product issues. Any R&D centre, developing diagnostic techniques, has not sufficient resources for conducting tests in conditions close to operational and for certification. Figure 1 illustrates new monitoring technologies implementation challenges.

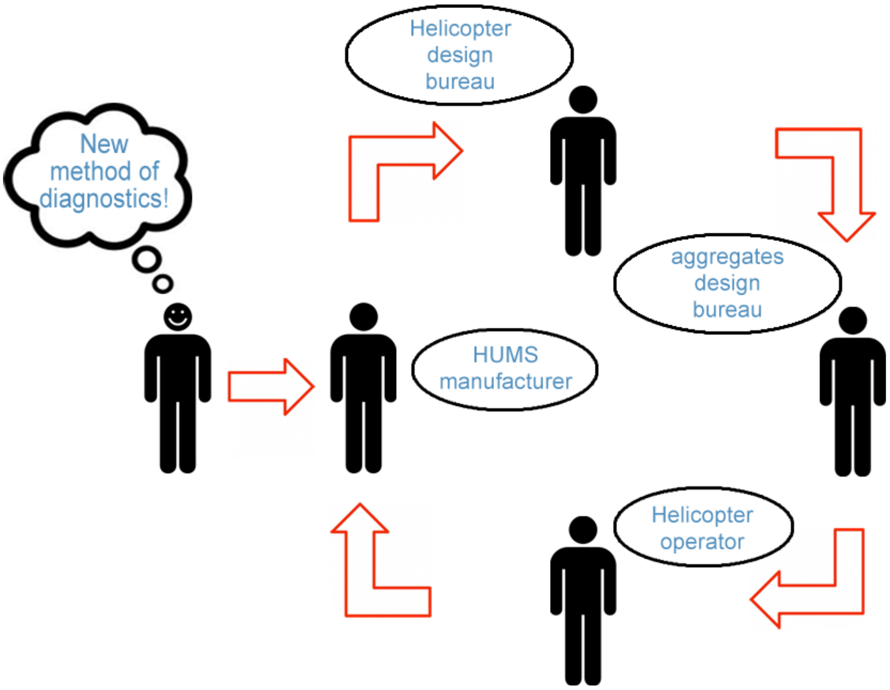


Figure 1. New monitoring technologies implementation challenges

Laboratories and R&D centres are already implementing in prototypes some components of in-flight vibration monitoring technologies, including:

- several aggregates of aircraft engines,
- main gear box planetary stages,
- bearings,
- blades and helicopter structure's members.

However, for these technologies reach a helicopter designer, a participant is needed capable to provide not only R&D works, but comprehensive tests as well, and if necessary – certification of the new technologies. The unique position of the RH as a holding, which combines helicopter designers and manufactures as well as of main aggregates, allows its Centre of Innovations & Competence (CIC) to provide the specified functions. Having conducted tests of new monitoring technologies the CIC then hands these technologies over to the holding enterprises.

The program of A-HUMS concept development realizing since 2011 is an example of such approach to implementation of helicopter aggregates new monitoring technologies. At first phase, main directions have been chosen:

- technologies of composite blades testing and monitoring, including in-flight;
- main gear box functioning monitoring techniques in a helicopter and as a part of testing bench,
- diagnostic technologies of helicopter transmission aggregates condition at testing on a bench and in-flight.

III. Technologies appraisal

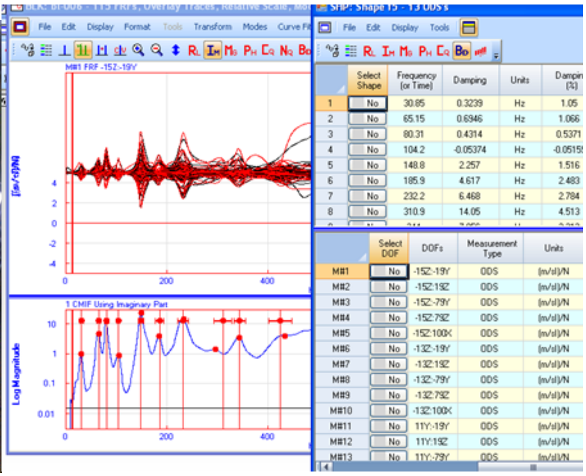
To demonstrate new technologies capabilities, its trial application is conducted at testing stands of a manufacture-plant and by the Aviation Research Center (ARC) in Riga, Latvia solving certain tasks of helicopter aggregates debugging. After successful completion of the stand testing phase, tests are conducted in full-scale conditions on a helicopter. At present, as a pilot project, testing by experiment of above mentioned as example technologies is carried out on *Ansat* helicopter aggregates in plant conditions.

A. Applying modal analysis for blade diagnostics

Experimental use of the modal analysis technology is carried out in two directions simultaneously: a study of composite blades dynamic behaviour in dynamic laboratory of the designer and experimental tests of technology's diagnosing abilities in the ARC.

At the designer, tests of technological sections of a new design composite blade, and *Ansat* helicopter solid composite blade are carried out. The main task of the tests is to evaluate applicability of the diagnostic technique to composite blades status by its dynamic behaviour. With this purpose, the evaluation of modal features of the blade is repeated in the course of its fatigue testing program that includes the combination of static and dynamic loads. The evaluation of samples' modal features is carried out by using the *frequency response function (FRF)* with the help of the so called *roving hummer* technique. Such approach allows determining operatively dynamic characteristics of the specimen, including mode's shapes, frequencies, and damping factors in the determined frequency band. Figure 2 illustrates the process of testing of a blade section, determining its FRF and oscillation shapes.

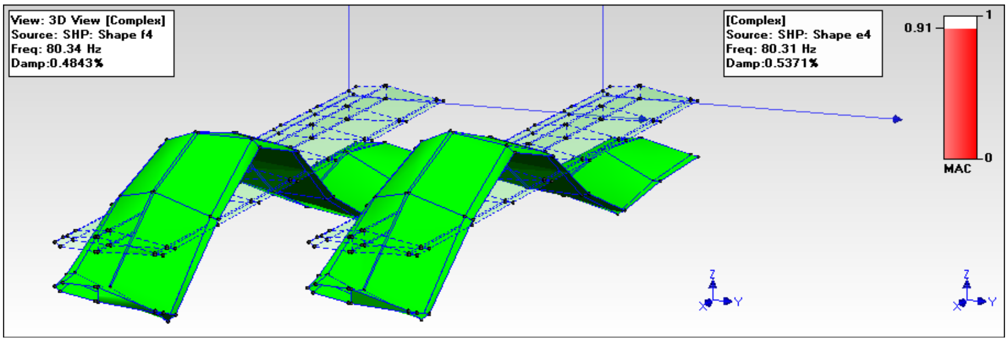
a



	Select Shape	Frequency (or Time)	Damping	Units	Dampin (%)
1	No	30.85	0.3239	Hz	1.05
2	No	65.15	0.6946	Hz	1.066
3	No	80.31	0.4314	Hz	0.5371
4	No	104.2	-0.05374	Hz	-0.0515
5	No	148.8	2.257	Hz	1.516
6	No	185.9	4.617	Hz	2.483
7	No	232.2	6.468	Hz	2.784
8	No	310.9	14.05	Hz	4.513

	Select DOF	DOFs	Measurement Type	Units
M#1	No	-15Z:-19Y	ODS	(m/s)/N
M#2	No	-15Z:19Z	ODS	(m/s)/N
M#3	No	-15Z:-79Y	ODS	(m/s)/N
M#4	No	-15Z:79Z	ODS	(m/s)/N
M#5	No	-15Z:100X	ODS	(m/s)/N
M#6	No	-13Z:-19Y	ODS	(m/s)/N
M#7	No	-13Z:19Z	ODS	(m/s)/N
M#8	No	-13Z:-79Y	ODS	(m/s)/N
M#9	No	-13Z:79Z	ODS	(m/s)/N
M#10	No	-13Z:100X	ODS	(m/s)/N
M#11	No	11Y:-19Y	ODS	(m/s)/N
M#12	No	11Y:19Z	ODS	(m/s)/N
M#13	No	11Y:-79Y	ODS	(m/s)/N

b



c)

Figure 2.

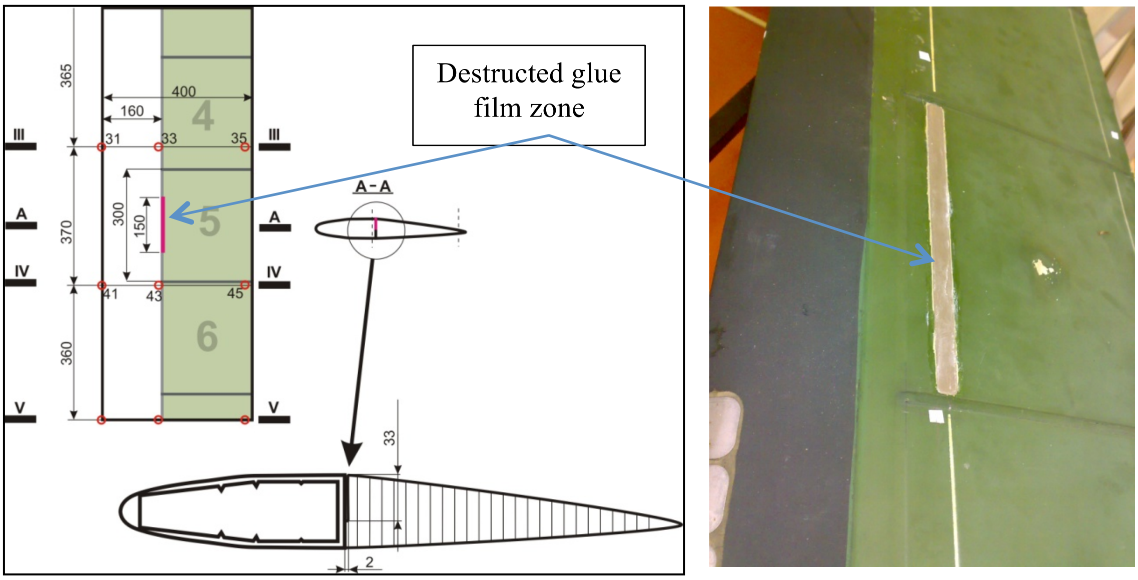
Illustration of a blade section stand test: a – blade in a resonant stand; b – evaluation of FRF; c – blade's oscillation shape (2-nd bending shape in thrust direction of).

Examination of the technique capabilities was conducted in parallel in laboratory and stand tests.

Laboratory test

In the ARC, the test was conducted on a section of a blade of traditional design (figure 3). The applicability of the technique was evaluated by its ability to detect a hidden defect occurring in operation, when a section of honeycomb comes unstuck from the blade spar back wall. Typically such delamination does not reach the blade skin and in operation, such defect is impossible to detect by existing non-destructive techniques.

The blade section was tested first in good state, then – in three faulty states with consequently rising scale of defect. A defect was created by destructing the glue film between the spar back wall and one blade tail section. The partially restored blade section was used as one more additional (fourth) test condition. Figure 3 shows the scheme of a blade section and a place of defect introduction (Figure 3a) and the view of the blade with restored outer skin (Figure 3b).

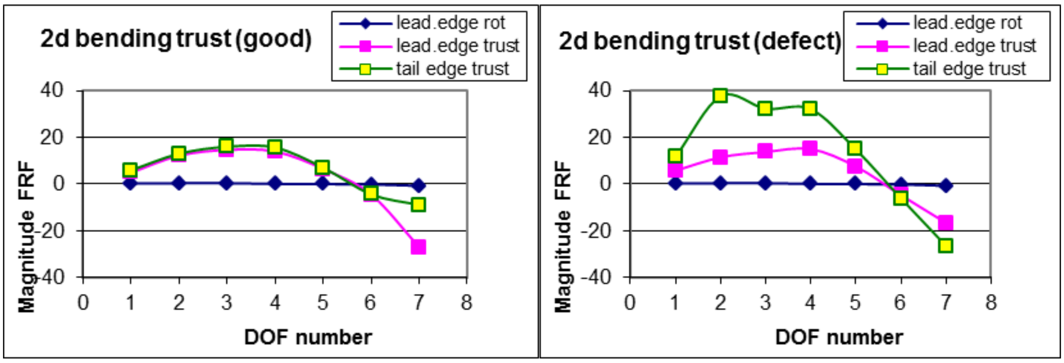


a

b

Figure 3. Scheme of a blade section and a place of defect (a) and the view of the blade after restoration (b)

The conducted study demonstrated change of all dynamic characteristics of the blade in response to the defect. Some modes proved to be more sensitive to a local defect, and change of their parameters formed the basis of blade diagnostics' parameters. For illustration, Figure 4 shows change of 2nd bending shape (in thrust direction), which is depicted with the use of character lines connecting FRF magnitudes in DOFs, which are distributed along the blade section length. The red line represents a curvature of the blade spar, the green one – of the blade tail part in the direction of thrust. The blue line represents deviation of spar's DOFs in rotation plain. It is noticeable that behaviour of both lines in Figure 4b (illustrating one of defect conditions) differs considerably from that of the lines illustrating mode shape of the "good status" blade section in Figure 4a.



a)

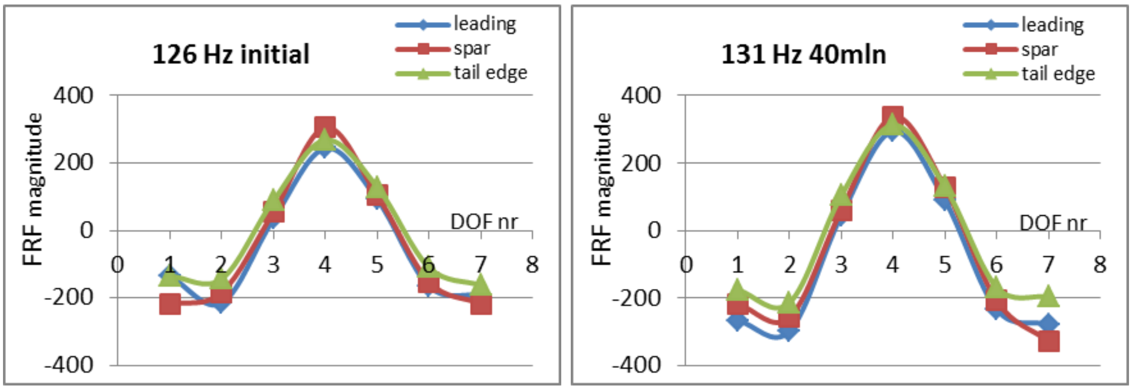
b)

Figure 4. Diagrams of FRF magnitude distribution along the section of traditional design blade: a – without defect; b – with defect of one blade section.

Diagrams show that the blade spar mode shape (red line) has changed a few, however the mode shape of the blade tail part (green line) has deformed significantly, responding to the introduced defect. In addition to the mode shape change, the introduction of the defect has also led to change of frequencies and damping factors of modes under study. Therefore, a local defect of the blade leads to change of all modal parameters, thus giving these parameters a diagnostic character.

Stand test

The composite blade sections' fatigue test, conducted in stand conditions, targeted to evaluation of modal testing technique capabilities for monitoring of blade's mechanical properties during its life cycle. The joint static and dynamic loads on the blade in the fatigue test series did not lead to any apparent faults, but produced multiple changes of shape magnitudes. As an example, Figure 5 shows the diagrams of FRF magnitudes distribution along the composite blade section at its oscillations on the 3-rd bending mode in thrust direction. Blue line refers to DOF on leading edge of the blade, red one – to rear wall of the blade spar and the green line – to tailing edge of the tested blade. Diagrams illustrate FRF calculated by test data at the beginning of the test (a) and after 40 million load cycles (b).



a) b)

Figure 5. Diagrams of FRF magnitudes distribution along the composite blade section during the fatigue test: a – in the beginning of the test;
b – after 20 million load cycles

The analysis of parameters has shown that endurance test modified all mode parameters. Frequency has grown up of 5Hz, damping has dropped down twice and magnitudes increased. So, modal testing has demonstrated a definite influence of fatigue changes on modal characteristics of most of identified modes. Therefore, the modal testing technology used allows evaluating the change of global mechanical properties of composite blade or other composite structure.

The tests of blades sections have demonstrated diagnostic abilities of the modal analysis techniques for monitoring of helicopter blade's status during both test and operation. At that, the modal testing technique allows to detect both local defects and global changes of mechanical properties, induced by fatigue, ageing and other causes. Continuation of tests will hopefully allow achieving not only qualitative evaluation of status change, but quantitative criteria of mechanical properties changes.

On the next stage of the technique development the modal test will be applied to a helicopter in field conditions. The test series is carried out with the purpose to implement the modal testing technique for full-scale objects' status monitoring.

B. Vibration diagnostics of the main gear box on a stand and in a helicopter

The appraisal of the main gear box monitoring technique was carried out on a testing stand of a helicopter plant with accelerometers installed on the tested main gear box and on the casing of the closing gear that provides work load.

By the way of the techniques trial application, certain tasks were targeted, including creation of a vibration passport of the main gear box and finding causes of increased vibration at testing of the main gear box on the test bench. The vibration passport was required by the designer to evaluate possibility of structural resonance occurrences of the helicopter structure. The main gear box vibration passport was created by application of an enhanced averaging technique allowing minimizing influence of factors that are not directly related to individual gear meshes running. Figure 6 shows a 3D diagram of vibration spectral composition of the most gear meshes under study.

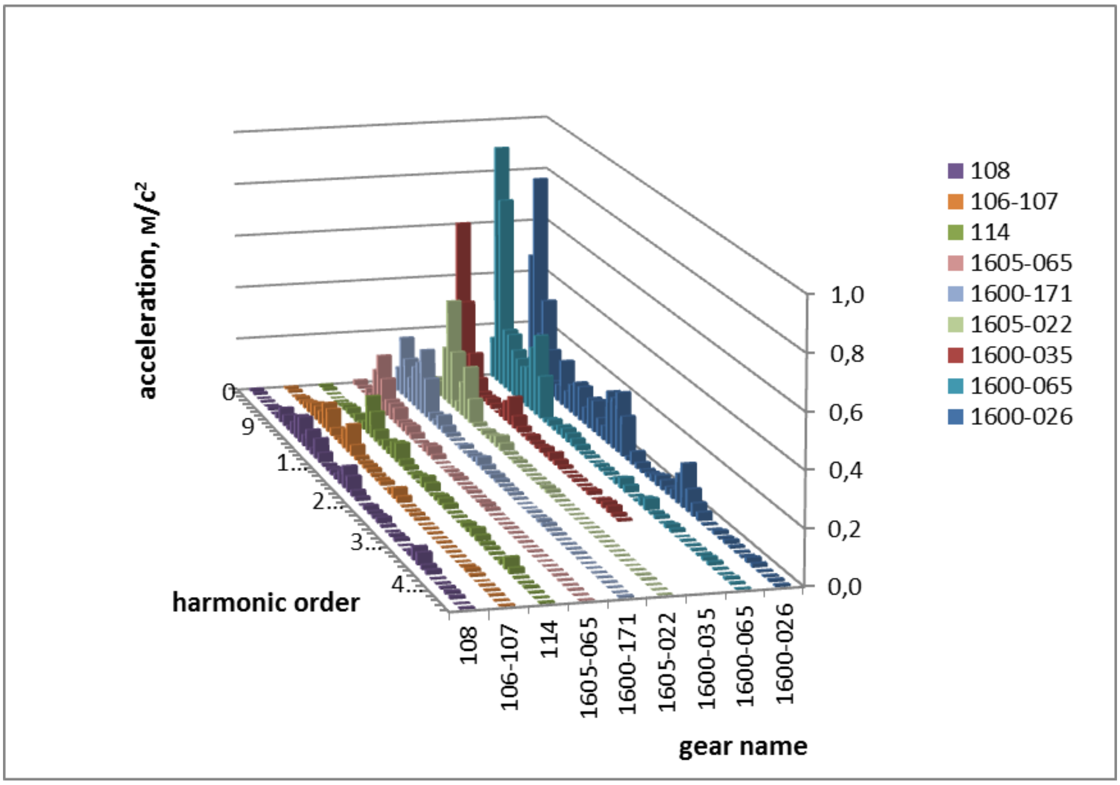


Figure 6. 3D diagram of spectral diagram of enhanced vibration signal generated by investigated gears

Vibration passport of the main gear box first of all allowed determining stable values of all significant components of vibration in the wide range of frequencies. Second – it was established that the levels and structure of these gear meshes vibration did not present danger from the point of view of possible resonances with helicopter structure members'.

The diagnostics of reasons of stand vibration increase at the main gear box testing was the second task of new techniques use. The conclusion on reasons of increased vibration was made on the basis of non-uniformity parameters of the main gear box and closing gears' meshes. These parameters have a structural nature and reflect ratio of accumulated energy in side harmonics of mesh frequency of enhanced vibration spectra. For example, Figure 7 shows spectral diagrams of enhanced signals of vibration:

- main gear box main rotor driven gear-wheel (blue) not manifesting irregularity non-uniformity, and
- driving gear-wheels (red) having significant non-uniformity.

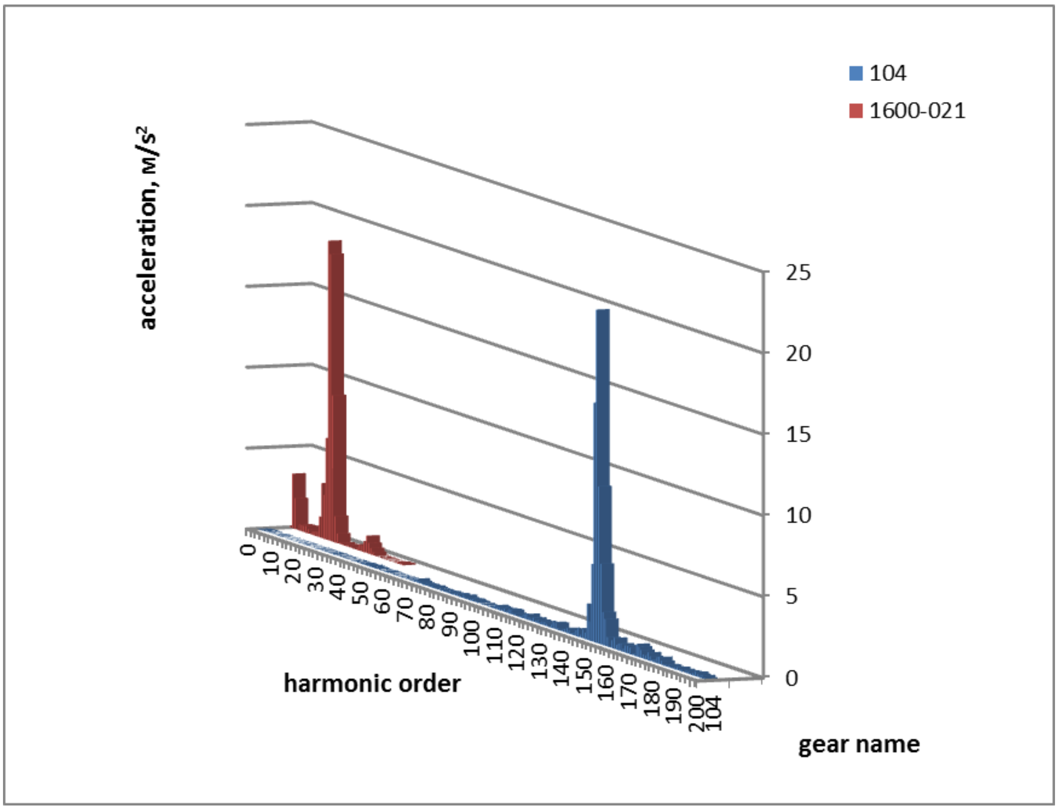


Figure 7. Spectral diagrams of enhanced vibration signal for both basic gears of the main gear box

The non-uniformity, which is produced due to a special way of work loading at the testing bench, is better displayed by signs of non-uniformity (side harmonics of enhanced spectra) of side (purple) and rear (green) driving gear-wheels of the closing gear of the stand (Figure 8).

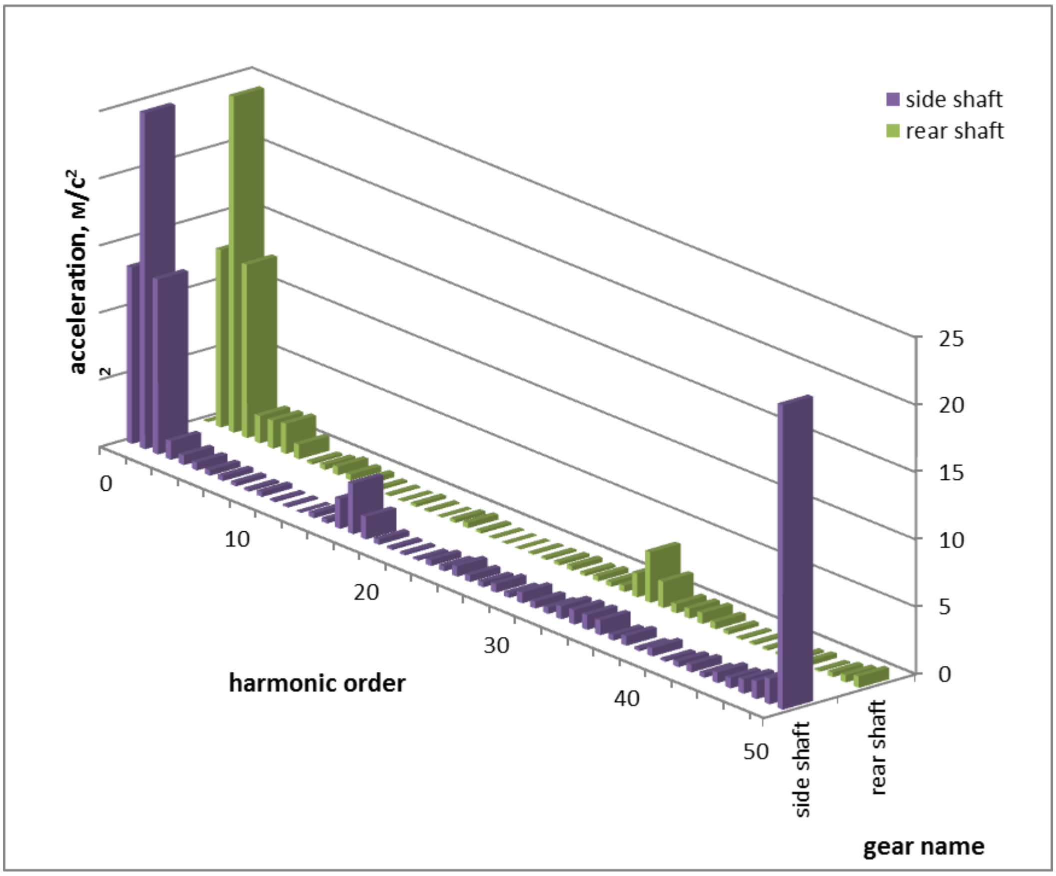


Figure 8. Spectral diagrams of enhanced vibration signal
of closing gear box basic gears

The tests performed on the main gear box are the first development phase of new diagnostic system for a main gear box, transmission and anti-torque rotor gear box of the helicopter.

C. Technologies' approval tests

In parallel with tests at designer site, the *ARC* is conducting works on development and debugging the technologies specified above. For these works ARC uses its testing facilities dedicated for testing and certification of vibration diagnostic and monitoring technologies. The facilities provide:

a) imitation of actual defects to verify and compare in practice functionality of different diagnostic techniques supposed to be used on a helicopter:

b) conduct full-scale measurements and a detailed analysis of vibration with the use of multichannel hard- and software as well as state-of-the-art signal processing techniques.

For rolling bearings as one of the most important part of machines the comparative study of different diagnostic techniques is conducted on the dedicated stand of bearing testing and on a stand of full-scale drive train (Fig. 9a).


a b

Figure 9. Test facilities for condition monitoring technologies testing: a – for the anti-torque rotor bearings and gear-trains; b – for the main gear box.

Typical technique based on envelope analysis of narrow-band random vibration was compared with new adaptive technique for rolling bearing diagnostics, based on accumulated energy of a wide band vibration signal, taking into account bearing kinematics. As opposed to the techniques currently used by HUMS, the adaptive technique does not require a large volume of tests for "tuning" the technology for a certain object. At the same time, due to self-dejaming, the technique can provide monitoring of not only drive-train bearings, but of the bearings that are difficult for diagnostics – main gear box, engine or, for example, lift rotor swash plate as well.

Technologies of main gear box condition monitoring are worked out on the main rotor-hub stand (Fig. 9b), which provides testing of monitoring technologies of gear-trains, swash plate's bearing, some parts of the main rotor head, as well as blade's sections. This stand will be used to work out a rotating blade dynamic parameters measurement and monitoring technique, effective technology of energy generation (harvesting) on rotating blade, as well as components of helicopter main rotor monitoring in-flight technology.

For aircraft engine and its aggregates testing and diagnostic techniques development ARC uses a unique stand on the basis of aircraft GTE (Fig. 10). The combination of a full-scale engine and an air duct vibration simulation system allows to research and to evaluate efficiency of existing and developing diagnostic techniques for all main units of helicopter engines in-flight.

Figure 10. Testing stand for aircraft GTE vibration diagnostic techniques

IV. Resume

The vertical-integrated structure of the "Russia's Helicopters" holding creates preconditions for development and implementation time reduction of Advanced-HUMS concept for the holding helicopter line-up. This concept includes state-of-the-art techniques of not only helicopter monitoring and diagnostics, but its maintenance as well. To shorten the way for the new technologies, the studies, experimental checks and appraisals on full-scale specimens are carried out simultaneously on plant's stands, as well as in a helicopter in field conditions. A special attention is paid to diagnostic technologies of bearings, including bearings of transmission, to gear boxes' gear-trains, to engines and to blades of the main and anti-torque rotors.