ADVANCED VIBRATION DIAGNOSTIC TECHNIQUES FOR OVERHAUL COSTS SAVING OF HELICOPTER ENGINES

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Abstract

Vibration excess is a typical reason of overhauled engines reprocessing. Aiming to avoid loses and to improve overhaul quality, the Ural Works of Civil Aviation started to apply advanced techniques for vibration diagnostics of tested engines. The system applying Excessive Vibration Sources Diagnostic Technique (EViDiT) allows identification of excessive vibration sources and provides diagnosis of operational conditions of main engine units during its testing. Application of EViDiT basic routines to tested engines is discussed, considering both engine and rig sources of excessive vibration identification. Results of research of testing rig modal properties and its influence on engine vibration are presented. Cases of diagnostic techniques application illustrate capability of EViDiT to identify the problem and to make corrections. Advanced options of the system are available for overhaul technology improvement and for post processing loses reduction using EViDiT for engine units' diagnostics. Perspective diagnostic techniques are discussed for air and gas flow duct condition diagnostics, bearings, gears and for accurate unbalance source identification. The paper considers benefits of above system application for overhauling company, including processing and post processing costs reduction, and also proposes new service in diagnostics and engine tuning in field conditions.

1. INTRODUCTION

Operation conditions of helicopter engines differ significantly from airplane ones. There are intensive wear due to dust, airflow duct erosion due to sea water, damages from external objects, intense operation modes in extreme situations, bad storage conditions and other adverse impacts. All above mentioned causes replacement of great number of parts in an overhaul of engines. These replacements affects interaction between old and new parts that can degrade performance of some aggregates as well as the whole engine. If the engine characteristics in an acceptance test do not correspond with the technical specifications, and it is impossible to adjust them on the rig, the engine has to be sent back to the production department for additional operations. Such works can mount up to 10% overhaul costs, in case if the precise reason of the problem is unknown. In order to make an optimal decision for the necessary tuning works, correct information about the source of the problem is required.

One of the key problems during the tests is the vibration excess beyond the permitted limits. Typical vibration measurement systems measure vibration during the acceptance test in the frequency bands that correspond to rotating speed of gas generator rotor (GG) and power turbine (PT). Therefore typical vibration parameter is 1st harmonic of vibration measured. Though this parameters is related directly to rotor movement, the excess of the limits might be caused not only by the rotor itself but by external source as well (fig.1). As *internal* factors can be the following: dynamic rotor unbalance (in case of adverse combination of compressor and turbine mass unbalance vectors), excessive aero-unbalance or abnormal operation mode of rotor supports. As the engine is mounted on a rig, Vibration measured by engine's transducer may be also caused by such external factors as a gap in the attachment points of an engine or the mechanical property modification of a rig structure. The factory is also faced by the costs that are not related directly to the technological cycle of an overhaul like excessive vibration, but also to the client's claims related to the engine being overhauled by the factory. The reasons for claim might be the coincidence of random factors, as well as divergence from technical specifications during overhaul. If one identifies abnormal operation modes of an engine during a test, then the corrective technological actions can be more profitable then the satisfaction of claims.

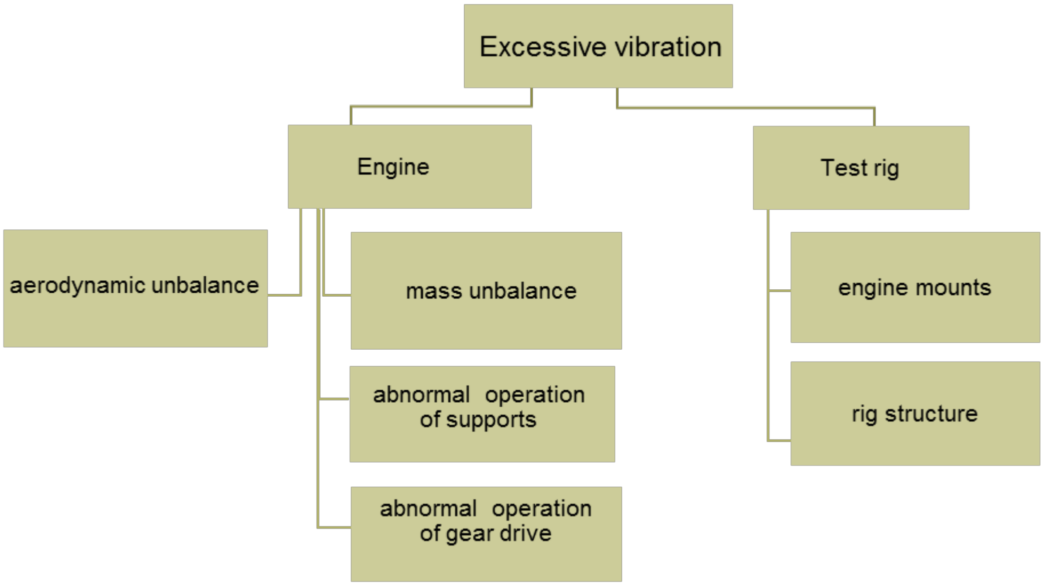


Figure 1. Typical reasons of excessive vibration of an engine.

Other problems may be errors in gears assembling, increased radial clearance in bearings, excessive temperature irregularity downstream the combustion chamber, reduced surge margin, etc.

In order to identify promptly specific reasons of excessive vibration and to reveal abnormalities of main units of the engine, the Excessive Vibration Sources Diagnostic Technique (EViDiT) is used during the acceptance test.

2. DIAGNOSTIC SYSTEM AND METHODOLOGY

This work presents preliminary results of the EViDiT application for TV3-117 engine at UZGA plant. The EViDiT is based on the approach considering both the engine and the stand as a complex dynamic system. Own dynamic properties of this system are influenced by internal and external factors. The assessment of the system properties is carried out using the Vibration Passport (the Vibropassport or VP) which includes set of diagnostic parameters and thresholds of these parameters. Vibropassport of the stand describes only mechanical properties of the stands structure using its modal parameters. Vibropassport of the engine is more difficult as it considers not only dynamic properties of its construction, but also variety of mechanical and aerodynamic interactions in the engine. To solve this complex problem VP of the engine is based on the physical models of engine vibration emergence and perspective methods of data processing using above models as well as state-of-the-art measurement tools (fig. 2).

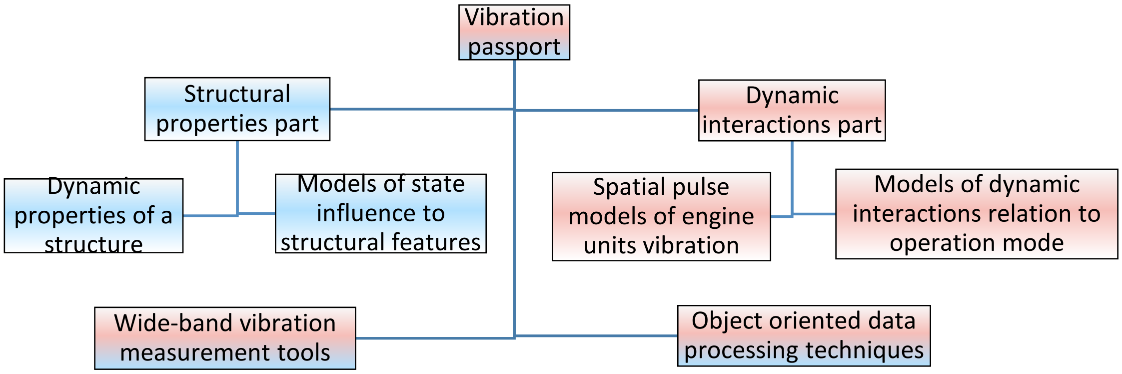


Figure 2. Vibration passport structure for test rig and jet engine.

Models of physical interactions consider an engine as a system that reacts to a set of correlated and uncorrelated quasi-periodical impulse sources of actuation that are spatially distributed. These models, considering, on one hand, structural properties of units, and on the other, the physical nature of interactions, describe the deterministic and random vibration components [1]. Based on above models the object-oriented data development techniques provide computation of VP parameters in time, phase and frequency domains [2]. The dynamic and frequency ranges, required by spatial and impulse models, are provided with state-of-the-art vibration measurement tools. Diagnostic parameters of VP have a relative scale and are not presented as velocity or acceleration units.

Configuration of the system, which executes the EViDiT technique, is presented in the fig. 3. The following signals come into the input of the measurement system:

- two 3-axial accelerometers installed on epy fitting at the front engine mount and on the flange of 4th support housing;
- synchronization signals of GG and PT.

The system is integrated into the rigs measurement set providing measurement and recording of signals according to technical specifications. Recorded data goes into the data base from where it comes into the PC of testing operator, where EViDiT processing software is installed. The data obtained from the engine is processed by SW modules for data development and parameters computation. Then the diagnostic SW module compares the computed values of diagnostic parameters to thresholds of these parameters.

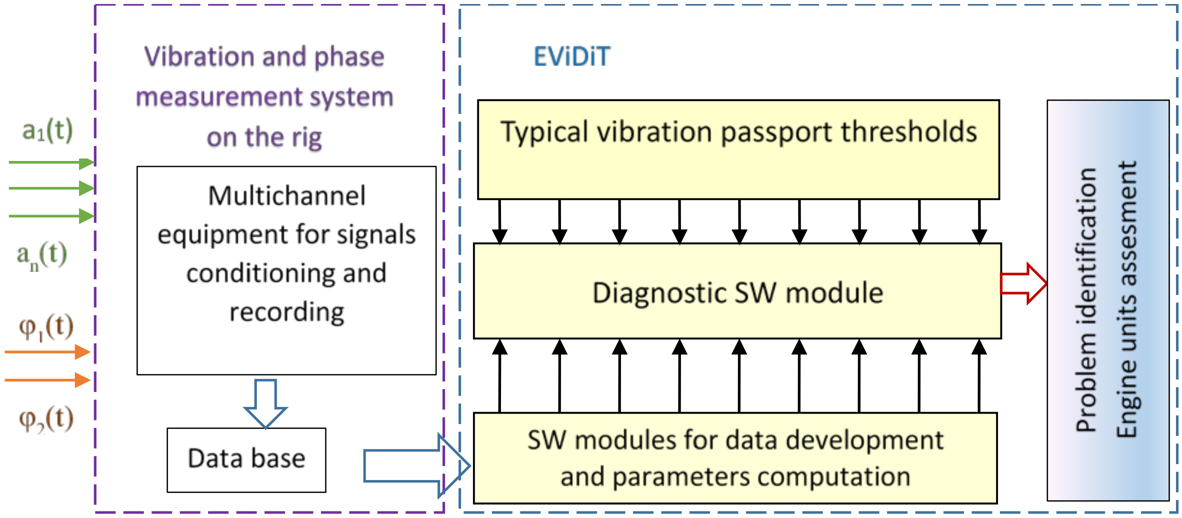


Figure 3. EViDiT system structure within the stand measuring body

After passing the acceptance test an engine obtains the assessment of operation quality of its principal units, but in case if vibration excessed thresholds - EViDiT identifies the most probable source of the increased vibration.

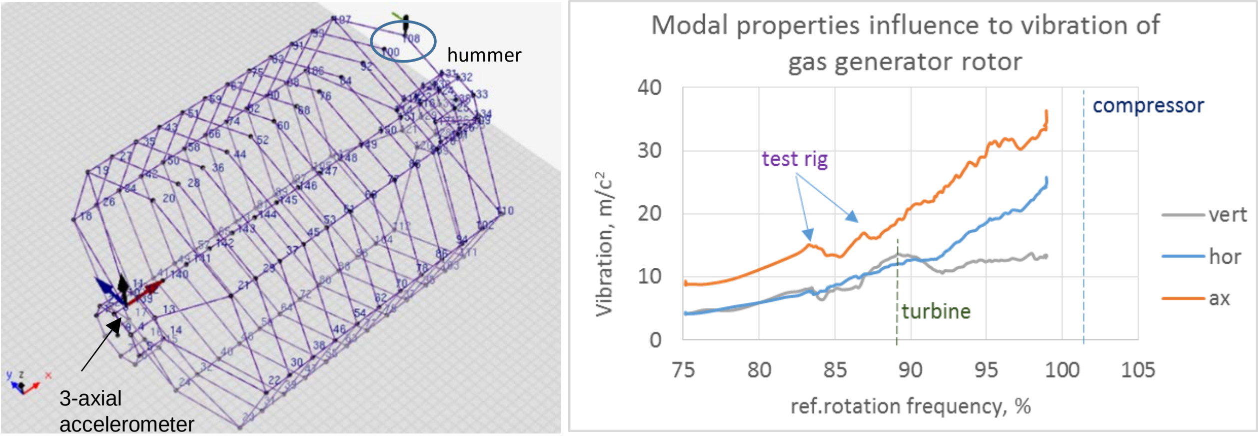
3. RESEARCH OF DYNAMIC PROPERTIES OF THE RIG-ENGINE SYSTEM

Vibration of engine housing is defined by rotor loads and dynamic properties of an engine construction. Therefore, vibration parameter may grow up because of both increased dynamic loads from rotor and modification of structural properties. For any engine these properties are individual and can have significant scattering from average ones. This can also influence vibration of a certain engine. Vibration level can be also influenced by the dynamic properties of a rig-engine system, therefore, the search for the reasons of excessive vibration needs to be started outside the engine. Thus application of vibration diagnostic techniques requires research of dynamic properties for both stand construction and engine units.

3.1. Identification of high vibration reasons of the engine

Dynamic properties of the engine appears in its vibration as resonances in frequency ranges, where rotation speed coincide with natural modes frequencies of a rotor. Research study of engine's dynamic properties included both modeling and dynamic testing of compressor and turbine rotors. As the sample of research study results fig.4a shows the geometrical model of compressor rotor and the layout of dynamic testing using a rover hummer technique.

Dependence of 1st vibration to referenced rotation speed of GG rotor presented on fig. 4b illustrates vibration influence of natural modes of the compressor, the turbine and the test rig as well. Such dependence comes from vibration analysis measured at a slow acceleration of the engine from idle to maximal operating mode. There are natural mode of the GG turbine (on 89% referenced rotation speed in vertical direction) and the compressor mode next to maximal rotation speed in operating range. Taking into account deviation of individual properties of engines the compressor mode may get into the working range.



a) b)

Figure 4. Modeling and dynamic test of compressor rotor:
a) – geometric model and measurement setup;
b) – vibration in vertical, horizontal and axial directions as a function of relative rotation speed.

Thus, natural modal properties of the engine play an important role in formation of vibration dependence from rotation frequency and the scatter of individual characteristics between engines can significantly influence vibration levels of a certain engine during the test. There is also influence of external factors, besides natural properties of an engine. Thus, on top of the influence of GG natural modes on axial vibration (fig. 4b) there are notable deviations from a smooth curve, for example, at 83% and 87%. The reasons of these changes were ben identified as external (test rig structure0, as there are no natural rotor modes in this range.

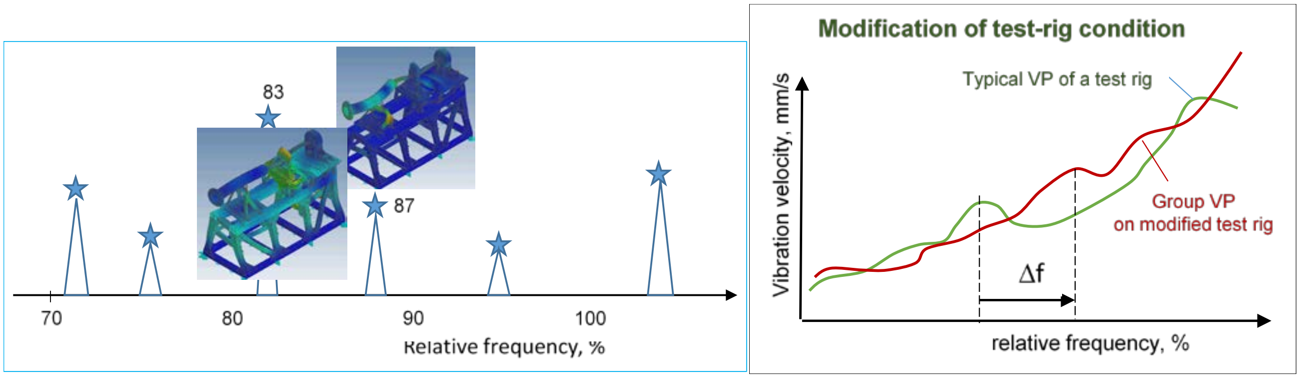
3.2. Identification of external reasons

3.2.1. Influence of the stand construction

To identify external reasons of engine excessive vibration it is necessary to consider dynamic properties of the test rig construction. Its research study includes:

- numerical modeling of the rig-engine system,
- modal parameters computation of the rig within frequency band of interest related to engine operation range,
- dynamic tests of the rig construction for the model verification,
- identification of modal parameters of the rig-engine system and the model tuning.

As the result the set of modes is defined within operational range of an engine and that are able to influence vibration levels. Such set of modes layout along referenced frequency axis with corresponding amplitudes and mode shapes indication we represent as VP of the rig-engine dynamic system (in fig. 5a). Any tested engine excites the rig structure at the modal frequencies (noted on the chart by stars) and the sensor on the engine housing measures the sum of both engine and stand vibrations. As an example of rig modal properties influence to engine vibration the two modes are provided by icons of mode shapes (fig. 5a). These modes are the reason of two small maxima of vibration elevation to relative frequency presented above in fig. 4b: 83% - the dominating rig intermediate support mode and 87% - the mode of the sub-motor frame.



a) b)

Figure 5. VP of rig-engine dynamic system: a) as layout with mode shape samples;
b) – illustration of system properties modification using vibration elevation vs. frequency diagram.

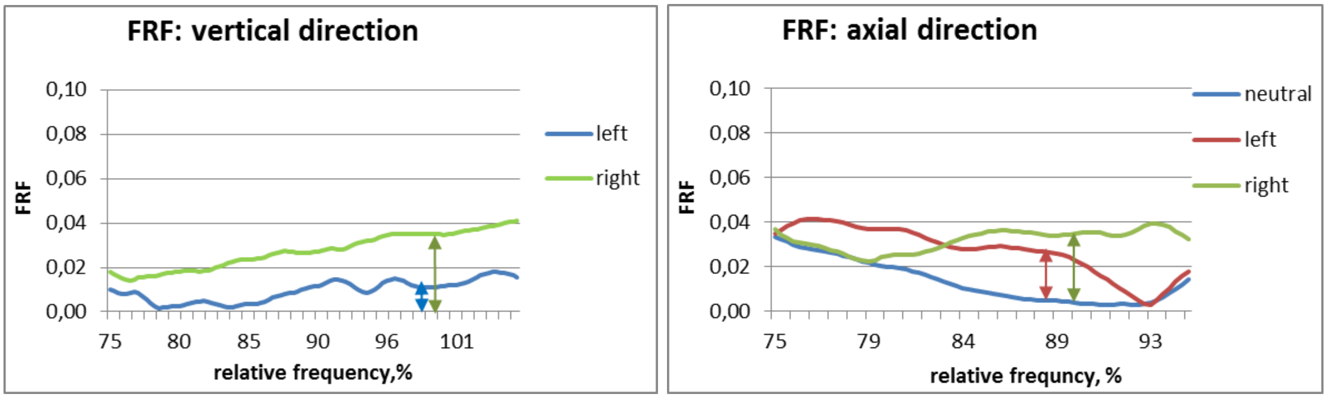
It is convenient to display typical VP of rig-engine system in the form of vibration function to operation mode (or relative frequency) allowing to consider also dynamic loads growth from idle to maximal operation mode. Such vibration function is computed based on engine vibration tests (on the rig) by averaging statistically valuable functions of vibration vs. rotation speed. Typical VP of the rig-engine system shown as a green line in fig. 5b is independent of individual properties of any engine but characterizes vibration of virtual engine dependence on working mode and proximity to natural modes. The rig-engine VP contains information on both resonances of the system and the ratio of its magnitudes, normalized to averaged engine excitation.

Mechanical properties are modified over time under the influence of dynamic loads from tested engines. The combination of various loading cycles leads to formation of cracks around stress concentrators, weld weakening and other defects. Such or similar changes can lead to natural modes frequency modification, pushing them closer to or out from the engine working range. This, in its turn, will influence dependence of vibration from rotation speed, causing increased vibration. Averaging vibration functions of serviceable engines group, the group VP could be obtained for condition monitoring of the rig-engine system (red curve on fig.5b). By the group VP matching to VP of the test rig, it is possible to reveal the deviations caused by modification of rig dynamic properties.

Known relation of vibration dependence to mechanical properties of the rig construction is used also for improvement of technological operations. For stand condition monitoring the vibration dependency is calculated using serviceable engines, which passed the tests. For this purpose vibration dependencies could be grouped for the engines with different criteria, including excessive vibration case or other reasons.

3.2.2. Influence of the rig attachment frame

The rig attachment frame may significantly influence engine vibration. Even small modification of rigidity (like a gap in a spherical bearing) or geometry (engine alignment on a rig) may change modal parameters of the rig-engine system, including vibration magnitudes. For example, quite often the intensive wearing under the influence of dynamic loads is the reason of emergence of bearings' gaps of connecting rods. Influence of potentially modifications of the attachment frame on the engine vibration was studied using experimental modal analysis methods. Rigidity of the attachment frame with and without a gap, was estimated using Frequency Response Function (FRF). The FRF dependences to relative frequency are presented on the fig.6, illustrating change of rigidity of attachment frame caused by the gap in the bearing of the left mount. Rigidity from the failed bearing side (blue curve) was 2-3 times less (fig. 6a), than the normal bearing (green curve). Such ease of attachment may lead to essential vibration growth irrespective of engine rotor unbalance.



a) b)

Figure 6. FRF of engine mounts as a function of its condition: a) “weak” left mount caused by a gap (right is normal); b) – tightening of mounts in case of centering modification.

Technical requirements allow some tolerances for engine alignment at the stand so engine centerline orientation may impact on attachment rigidity. Research of engine orientation influence to vibration was conducted by deviation of an engine axis in relation to the stand axis. Such deviations were carried out using adjustment of connecting rods of the engines alternately from the right and from the left (without gap in bearings). From the chart on fig. 6b it is seen that shift of the engine axis from neutral position (blue curve) led to noticeable increase in rigidity of “compressed” attachment, influencing engine vibrations. It should be noted that similar adverse influence to an engine attachment can be identified using the rig-engine VP as it was shown above.

Thus, the analysis of dynamic characteristics of the rig-engine system and the attachment frame showed the scale of their influence on engine vibration and facilitated the rig-engine VP required for diagnostics of engines.

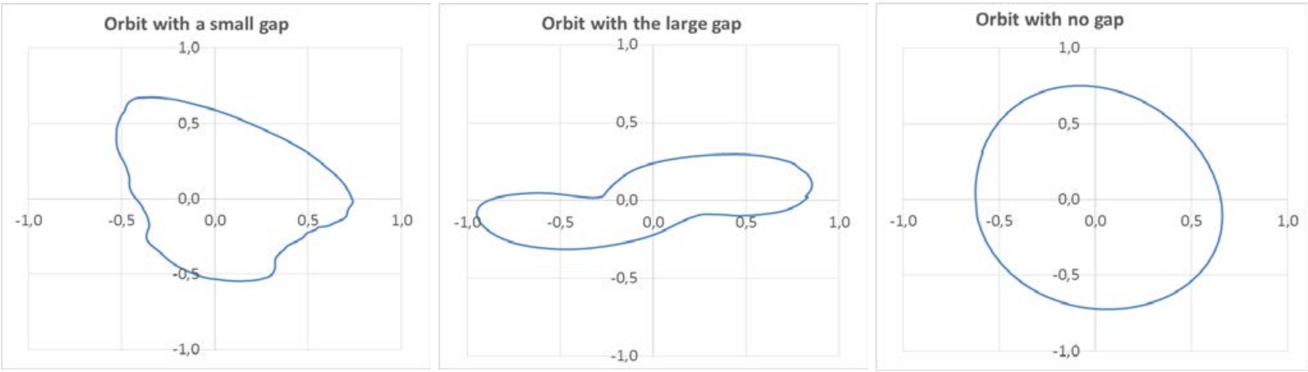
4. IDENTIFICATION OF EXCESSIVE VIBRATION IN AN ACEPTANCE TEST

As engine vibration depends on various factors in case of vibration excess, EViDiT first of all identifies the reason: engine itself, attachment frame or properties of the rig.

4.1. Diagnostics of the stands attachment frame

The technique estimates the weakening of an engine attachment using engine housing velocity distribution along a phase. This parameter is estimated in two orthogonal directions in a relative scale by normalizing the values to the velocity magnitude. The orbit of engine oscillations on the rig depends on mechanical properties of the attachment frame, which influence is expressed in position of the center and roundness of the orbit. Computation The standard orbit is computed on statistically proven sampling of serviceable engines with no gaps in attachment. Besides an average trajectory the standard orbit includes also standard deviation determined by the same sampling. In case if orbit shape and center position of the tested engine go beyond rated deviation, it indicates vital modification of attachments properties, including possible emergence of gap.

As an example, orbits of three engines are shown on fig. 7. These engines were tested on the same stand with a gap in the attachment frame evolving during 2-4 months: a small gap in the bearing of one connecting rod (fig. 7a), the maximal admissible gap (fig. 7b) and no gap (after replacement of the rod’s bearing with a new one) (fig. 7c).



a) b) c)

Figure 7. Orbits of the engines tested on the rig: small gap (a), maximal gap (b) no gap after bearing replacement (c).

It should be noted that the engine with the orbit like presented on fig. 7b (maximal gap) may have many times more vibration. Therefore, EViDiT system monitors attachments state automatically by the orbit measured matching with a standard orbit of this stand, even if parameters of engines vibration satisfy the limits.

4.2. Stand construction condition monitoring

Modification of mechanical properties of the rig structure leads to distortion of its vibropassport, as it was illustrated on fig. 5. Respectively, measured rotor vibration of the engine tested on modified rig will be corrupted. As was discussed before, the vibration dependence to mechanical properties of a testing rig can be used for condition monitoring of rig’s structure using deviations of clustered relations of vibration on the typical rig-engine VP. However, to allocate the distortions brought by the stand it is necessary to eliminate vibration relations to other factors, including individuality of any engine vibration, rate of engine acceleration during a test, atmospheric conditions, engine temperature, etc. EViDiT carries out automatic condition monitoring of the rig based on periodic matching of group VP to the typical VP of rig-engine system is carried out periodically to reveal shift of resonances of the stand on Δf, which can lead to vibration increase as it is illustrated on fig.5b. Frequency range of the revealed deviation of group VP allows to localize the zone of the rig structure for the facilitated NDT survey and fault detection.

The approach described above is used also for solution of technology improvement problems (p.3.2.1).

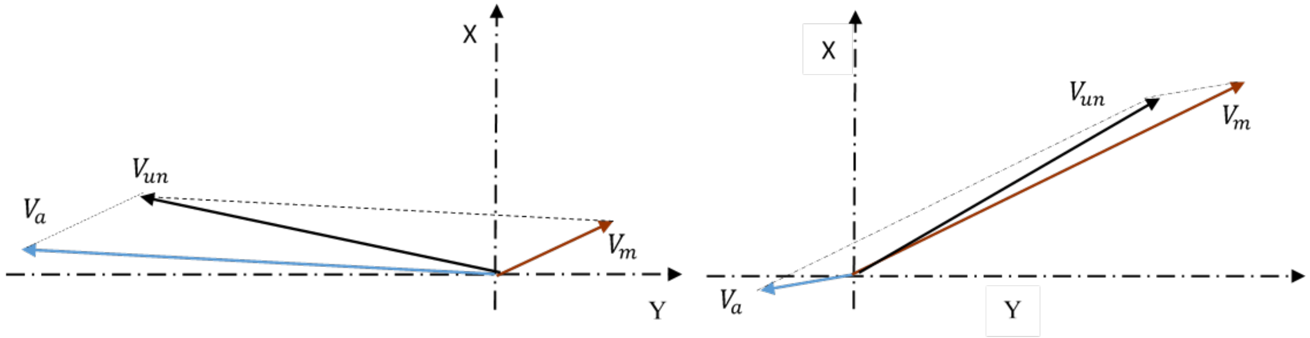
If diagnostics of engine attachment frame or the rig structure doesn't reveal changes of their state, search of high vibration sources is carried out inside the engine.

4.3. Excessive rotor vibration diagnostics

Engine diagnostics begins from its rotors, which unbalance is the most typical reason for vibration increase. Rotors of turbomachines may have an unbalance of mass and aerodynamic origin. The first one arises because rotation axis does not coincide with stator axis, the second – because trust vector created by rotor does not coincide with its rotation axis. This discrepancy arises because trust vectors of any rotor stage do not coincide with rotation axis that is caused by scatter of blades aerodynamic properties in a stage. Total trust vector of a rotor (a sum of stage vectors) is also displaced in relation to rotation axis. That is whyt, EViDiT defines the dominating type of unbalance, and then defines its reasons.

4.3.1. Rotor unbalance origin

As the first step, EViDiT defines ratio between vectors of aero- and mass unbalances, applying to 3-dimensional vibration signal the data development techniques based on the spatial model of rotor-stator interaction. The vector diagram on fig. 8 illustrates the examples of first step – vector diagrams demonstrating the ratio between vibration vectors caused by aerodynamic and mass unbalances. The examples are given for GG of two actually tested helicopter engines with different ratio of aero- and a mass unbalance.



a) b)

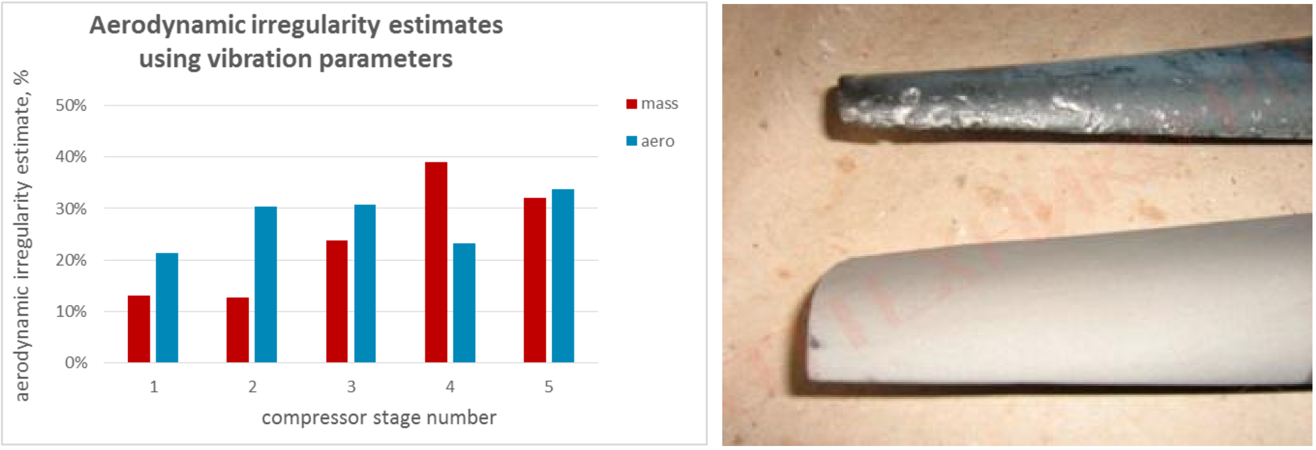
Figure 8. Vector diagram of vibration components caused by unbalance:
a) – aerodynamic vibration ($\boldsymbol{V_a}$) dominates, exceeding total unbalance vector ($\boldsymbol{V_{un}}$);
b) – mass unbalance ($\boldsymbol{V_m}$) dominates.

From the chart in fig. 8a it is visible that in the given example the aero imbalance vector (blue) was dominating in the engine, where a large number of blades was replaced by renovated ones (fig.9b). Aero unbalance parameter in this case was three times larger, than for the engine with original set of blades, at which the contribution of aero unbalance was minimal (fig. 8b).

After the dominant cause of unbalance is established, localization of unbalance source is carried out in order to reduce added processing costs required for the engine tuning.

4.3.2. Aerodynamic unbalance sources

Aerodynamic unbalance of a rotor is the vector sum of such unbalances for all blade rows (compressor or turbine), thus their contribution to total unbalance depends on various factors. Design, manufacture factors (technology and skill) and operation mode factors (an operating mode, atmospheric conditions) have their influence.



a) b)

Figure 9. Comparative estimation of 1-5 compressor stages aero unbalance for two engines (a); teared and restored blades (b)

EViDiT estimates the contribution of each compressor stage to aero unbalance using spatial-impulse model of engine vibration [3]. Diagnostic parameters of the engine VP called aerodynamic irregularity estimates are computed to localize dominating sources of aero unbalance – the stages with increased aerodynamic irregularity of a blade row. On fig. 9a the histogram compares the estimates of the aero irregularity of the first five compressor stages of two above mentioned engines, which vector charts were provided on fig. 8. The engine (fig. 8a) with the dominating aero unbalance (blue) has more aerodynamic irregularity almost on all stages than the engine (fig. 8b) with mass unbalance (red) at which aero unbalance prevailed only at the 4th stage.

In such way application of VP parameter of aerodynamic irregularity allows to identify those stages of compressor, which cause aero unbalance of the rotor.

4.4. Mass unbalance and other reasons vibration excess

Besides aero unbalance operating engine has also other sources of vibration growth, including an adverse combination of several factors. Significant increase of typical vibration parameter can happen at an adverse combination of unbalance locations of compressor and turbine. Sometimes, turbine vibration may increase if considerable unevenness of temperature field behind the combustion chamber causes corresponding unevenness of flow velocity upstream of turbine blades. Bigger gaps in bearings of engine rotors or central drive gears assembling errors can become the reason for excessive vibration also. Above mentioned reasons may cause growth of typical vibration parameter and EViDiT provides identification of vibration excess sources.

5. DIAGNOSTICS OF THE ENGINE UNITS

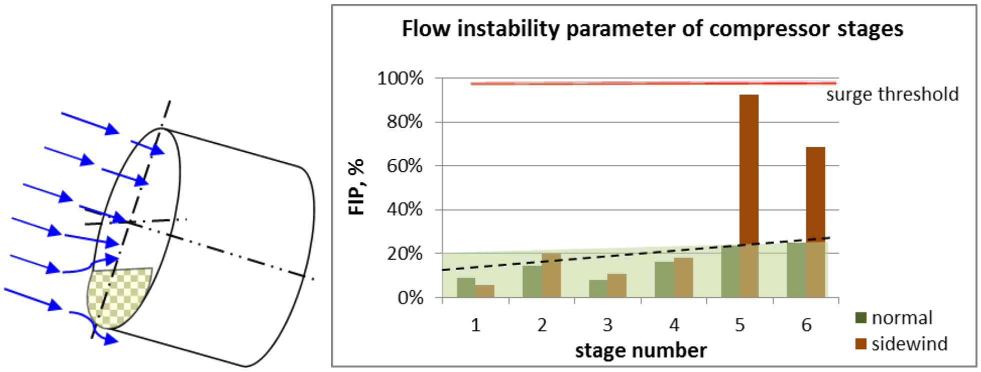
Though typical vibration parameter (1st harmonic) has diagnostic sense for problems of engine rotors, it does not respond to many abnormalities of principal engine units, which can take place in the tested engines. These abnormalities can reduce engine performance and service life, causing its early failures and claims from customers. Therefore, it is important to assess functioning of key engine units when it is tested and if necessary to tune additionally specific ones. If problems repeat and are related to more than one engine, might be some technology operations needs to be corrected. For above problems solution the EViDiT system estimates dynamic aspect of units operation in the engine test. There are examples below demonstrating application of VP diagnostic parameters for assessment of engine units' operation condition during test on a stand.

5.1. Surge margin diagnostics of the compressor

Reduction of surge margin may happen at compressor's high pressure stages under the influence of various factors, for instance inappropriate tuning of controlled guide vanes. Low surge margin of engine compressor can present a serious problem for the customer, especially when his helicopters operate in hot climate and highlands.

For surge margin diagnostic EViDiT assesses decrease of gas dynamic stability of a compressor using VP parameter that characterizes the intensity of flow turbulence around blades [4]. Based on the technique considering impulse model of blades-vanes interaction, EViDiT computes the parameter for each compressor stage for potential surge localization. In normal operation mode the parameter of a stage instability varies from 5-15% at low pressure to 20-30% at high pressure stages. The closer the stage is to a surge mode, the closer is the gas dynamic stability parameter to 100%. For an illustration, the technique application is shown in fig. 10, where the results of the experimental throttling of the tested engine are given.

Air throttling of the engine intake, imitating crosswind (fig. 10a), displaced working point of the compressor on pressure line to surge border. After the surge border was established, the test of the engine was carried out on operation mode 2% less than surgical mode to keep the minimal margin of stability. On this critical operation mode (close to surge border) VP parameter values of gas-dynamic stability were computed for each stage. Fig. 10b demonstrates comparison between critical mode parameters and corresponding values at a normal operating mode of this compressor. As seen from the chart, the flow instability parameter at the normal operation of the compressor does not exceed 20-25%, however if throttled, the parameter at the 5th and 6th increased to 70-90%. Frequency range limits of applied measurement system did not provide assessment above the 6th stage.



a) b)

Figure 10. Air throttling of an engine (a) and bar graph of flow Instability Parameters (FIP) of six compressor stages in different conditions (b).

Application of above technique of surge margin estimation allows engine shop to reduce risks of claims from customers. This technique could also be the tool for control of surge margin when guiding vanes regulation is necessary in field conditions.

5.2. Diagnostics of gas flow unevenness downstream from combustion chamber

Abnormalities in hot gas path of the engine threatens both for engine performance and operating life decrease. The EViDiT provides assessment of peripheral flow irregularity actuating a turbine. The main source of flow unevenness a turbine upstream is flame torches generated by fuel nozzles in combustion chamber and form a flow of hot gas in an operating engine. Unevenness of this flow field can be considerable that creates additional thermal and aerodynamic loads on turbine blades. Some flow distortion of a flow may arise also in case of nozzle guide vanes partial disintegration. Modification of dynamic loads caused by flow irregularity is measured by vibration sensor on the engine housing and can be identified using VP techniques.

The impulse model of blade-flow interaction considers design features of a combustion chamber and a gas path and allows estimation of irregularity coefficient of a combustion chamber downstream in a relative scale. On fig. 11 the histogram shows irregularity coefficients for hot gas that are the results of test experiment on the operating engine.

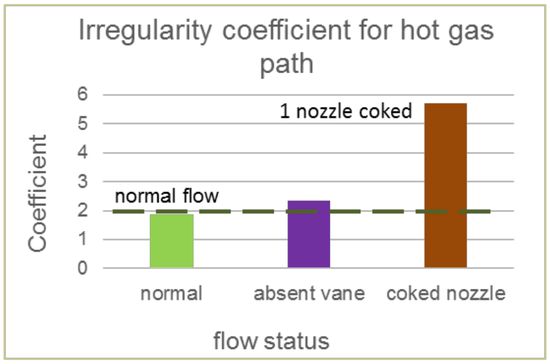


Figure 11. Bar graph of flow irregularity coefficient in relation to flow status

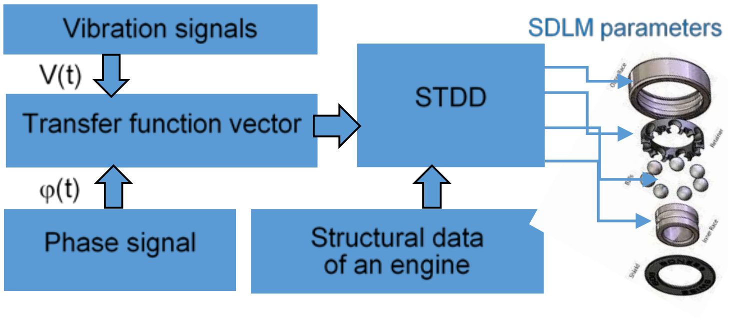


Figure 12. Adaptive diagnostic technique for rolling bearings

In the experiment two typical failures of hot gas path were simulated. In first test one nozzle vane was removed from guide vane of 1st turbine stage. In second one the fuel collector was replaced in the combustion chamber: the origin collector was replaced with another one where one nozzle was coked. At the normal operation mode with original fuel collector (green bar) the irregularity rate remains below 2.0. Single guide vane failure (violet bar) slightly exceed the threshold of normal rate, but coking of one nozzle caused growth of coefficient three times (brown). So, the irregularity parameter of hot gas path applied during engine test allows to detect imperceptible (by existing methods) abnormalities of the operating combustion chamber and to eliminate its adverse consequences, like serious failures in operation.

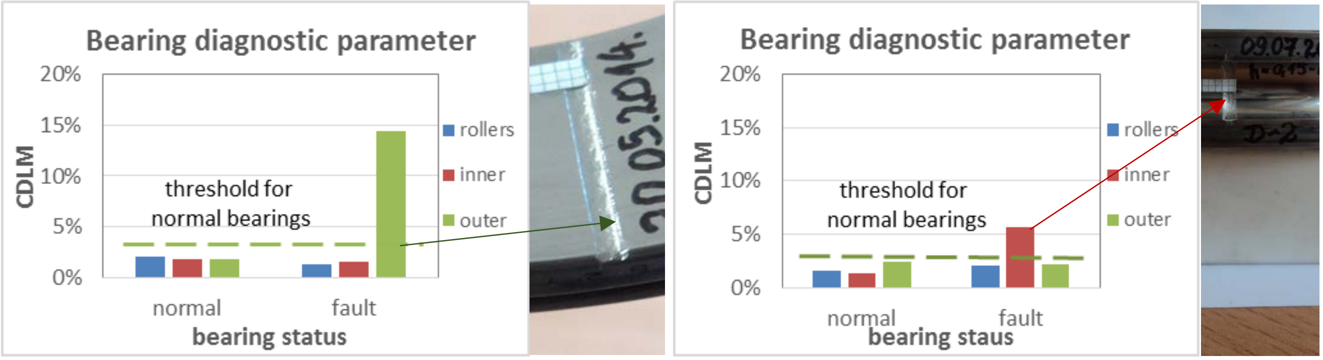
5.3. Bearings diagnostics

The EViDiT estimates engine bearings condition using adaptive vibration diagnostic technique [5] as part of engine VP. Using wide band frequency vibration signals and the signal of rotation phase the system estimates the condition of bearing's components racetracks: outer and inner rings, rollers/balls, cage and radial clearance, as well as the state of the damper of rotor's support (if there is one). Though overhauled engine shouldn't have defects of rotor bearings, the problems are possible, for example, because of increased gaps or a swash of external or internal rings.

The adaptive technique unlike other methods of bearing diagnostics do not use selected components of vibration, but extracts a transfer function of the bearing in a time domain. It allows to apply relative rating scale that is universal for the majority of bearing types. From transfer function the adaptive technique obtains parameters of racetracks condition (fig. 12) by applying the mathematical method of data processing that is called Spatial Time Domain Distribution (STDD).

Diagnostic parameters obtained by STDD estimate the influence of racetrack roughness and radial gap as the dynamic loads transferred by the bearing to the engine housing. Value of the parameter in a relative scale shows how this or that part of a bearing increases dynamic loads in comparison to loads transferred from the rotor, therefore parameter is called Coefficient of Dynamic Loads Multiplication – CDLM. Zero value of relative CDLM scale corresponds to ideal bearing (with gap tending to zero, with ideal racetracks and rollers). 100% of CDLM scale is equivalent to double (as against rotor loads) increase of dynamic loads on the housing caused by faulty bearing. Thanks to the relative scale the adaptive technique allows to fix thresholds for defects of engine bearings without preliminary tests applying the data obtained from other bearings tested. For gradual calibration of CDLM scales of various bearings damage types it is enough to carry out bearing tests on a specialized testing rig, therefore, there is no need for expensive experiments on the operating engines.

Fig. 13 illustrates sensitivity of adaptive technique in relative scale to two testing faults of the bearing: the front bearing of the compressor of the turboshaft engine (fig. 13a) and the helicopter swashplate bearing (fig. 13b).



a) b)

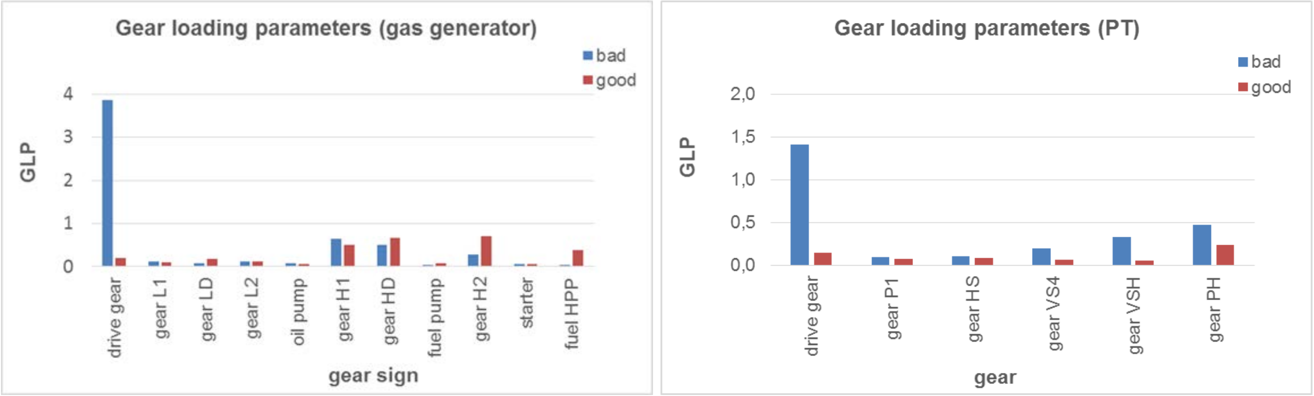
Figure 13. Illustration of relative scale of adaptive technique parameters: a) – turboshaft engine bearing - test fault of outer race; b)- helicopter swashplate bearing - test fault of inner race.

Racetracks of practically new bearings typically have CDLM parameters between 3-5% for the most types of bearings. Emergence of cross scratch 0.15 mm in depth and 2 mm wide on the outer racetrack increases CDLM almost to 15%. Approximately same defect on the internal racetrack of the bearing of the swash plate causes smaller change, but sufficient to go beyond the threshold (green dashed line).

5.4. Gears Diagnostics

The EViDiT reveals abnormal mode of operating gears during engine acceptance test on the rig. Gears abnormal operation can be caused both by adverse confluence of random factors, and the errors permitted at assembly of gears.

The EViDiT diagnostic parameters for engine gears are intended for assessment of gearing operation “quality”. Vibration diagnostic parameter of each gear evaluates influence of input or output power flow on dynamic loads generated by the gear. Gear Loading Parameters (GLP) are estimated as the ratio between vibration components excited by gear wheels rotation and tooth meshing interactions therefore they have relative scale. For normally operating gear GLP typically does not exceed 0,5. In case of parallelism or perpendicularity of gear axes problems, influence of input or output gear wheel on dynamic loads dramatically increases, thus GLP can significantly exceed 1,0. On fig. 14 bar graph demonstrate comparison of GLP estimates for gears of gas generator and power turbine between "good" and "bad" engines.



a) b)

Figure 14. Bar graph of Gear Loading Parameters (GLP) for gears of “good” and “bad” engines: gears driven by GG (a) and gears driven by PT (b)

It is visible that GLP of drive gear of the "bad" (left blue bars) engine of both GG and PT is significantly higher 1.0 that points to abnormal operating mode of gearings of the leading gear wheels of both rotors. The reason of such abnormality can be some deviations from technical requirements at gears assembling stage.

The examples given above clearly demonstrate possibilities of VP diagnostic parameters not only in identification of sources of excessive vibration, but also in diagnostics of principal engine units by the way of acceptance test.

6. POSITIVE EFFECT OF EViDiT APPLICATION

The EViDiT applied at an engine testing provides detection the reasons of excessive vibration of the engine, identification of the sources and thereby reduction of the volume of necessary additional works for engine tuning. For engine workshop the benefits are expressed in labor costs reduction, decrease in fuel consumption, expendables and the electric power, in decrease of damageability of reusable spare parts and in release of production facilities for increase in outputs.

Application of the diagnostic techniques provides advantages also to customers as overhaul terms are reduced, the operating time of the engine is increased and amount of spare parts needed for overhaul is decreased. Each engine repaired by the engine shop can have individual VP allowing the customer to provide not only monitoring, but also diagnostics and prognostics of principal engine units in operation using vibration diagnostic parameters.

Besides improvement of overhaul technology the engine shop can offer additional services in diagnostics of engines in field conditions on the market, using portable version of the diagnostic system. Using its capabilities of in-depth diagnostics of helicopter engines in field conditions the engine shop can provide compressor tuning to control surge margin, assessment of bearings and gears condition, wear and corrosion of blades and vanes, coking of combustion chamber nozzles and other defects.

Creating such opportunity, the engine workshop gets essential competitive advantage on the market of helicopter engine maintenance and repair.

7. ACKNOWLEDGEMENT

The paper uses materials related to research “The Study of Dynamic Properties of Aviation Engine Aggregates for Vibration Diagnostic Technology Research and Demonstrator Development” of the project „Establishment of Engineering Systems, Transport and Energy Competence Center” in cooperation with Central Finance and Contracting Agency of Latvia. This work contains the results of the research and the development of the technical requirements for engine aggregate test rigs.

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