TRANSPORT PROBLEMS 2009
PROBLEMY TRANSPORTU Volume 4 Issue 3 Part 2

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DIAGNOSIS OF THE JET-PROPELLED ENGINE BY VIBRATION ANALYSIS

Summary. In this paper presented works connected with the preparation of the active experiment with the jet-propelled engine. The experiment was prepared and done at the Air Force Institute of Technology. The main aim of this preparation was the explanation of the causes of the damages of military aerial ships after air incidents, notified damages in the process of exploitation and obtainment of the vibration answer on simulated damages.
The exit test of the jet-propelled engine was the point of the reference after the repair in the Military Aviation Depot.

DIAGNOZOWANIE SILNIKA ODRZUTOWEGO METODĄ ANALIZY DRGAŃ

Streszczenie. W referacie przedstawiono prace związane z przygotowaniem eksperymentu czynnego, jego wykonanie na silniku odrzutowym SO-3 na stanowisku do hamowania silników lotniczych zlokalizowanym w Instytucie Technicznym Wojsk Lotniczych. Eksperyment miał na celu wyjaśnienie przyczyn uszkodzeń wojskowych statków powietrznych po zaistniałych wypadkach lotniczych, zgłoszonych uszkodzeniach w procesie eksploatacji oraz uzyskanie odpowiedzi drganiowej na symulowane uszkodzenia.
Punktem odniesienia była próba wyjściowa silnika odrzutowego po remoncie. Eksperyment został podzielony na kilka etapów, w których wprowadzano do konstrukcji silnika uszkodzenia w celu analizy odpowiedzi drganiowej korpusu silnika na zadane uszkodzenia.

1. INTRODUCTION

Detecting and diagnosing damages in jet-propelled engines by the vibration analysis of the case the engine is very essential question from the point of the view of maintenance and the safety of flights and continuous exploitation. Acquisition and the suitable analysis of vibration signals can allow to detect the damages of bearings, units on the case of drives, etc.

In this paper presented works connected with the preparation of the active experiment with the jet-propelled engine. The experiment was prepared and done at the Air Force Institute of Technology. The main aim of this preparation was the explanation of the causes of the damages of military aerial ships after air incidents, notified damages in the process of exploitation and obtainment of the vibration answer on simulated damages.

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2. DESCRIPTION OF THE OBJECT

The bearings (front support - ball bearing, central and back support – roller bearing) they make up the crucial element of the assurance unfailing work and the safety of flights with jet-propelled engine. Bearings transfer strengths working on the shaft with the shields of the compressor and turbine. The damage of the rolling bearing of the central support is the most problem of this type jet-propelled engine (SO-3). The damaged bearing generates the impulses of damped vibrations with frequency dependent on free vibration frequency. These impulses repeat themselves in dependence from the frequency of the turn of the shaft of the jet-propelled engine which the in the case of the studied object are from 6900 r.p.m. to 15600 r.p.m. and the constructional features of the bearing. To do suitable kinematics convert can obtain characteristic frequencies which can allow to detect of damage: external track, internal track, rolling element, bearing separator.

The measuring system consist of: card A/C with loading amplifiers and the piezoelectric sensors of vibrations. The vibrations pick-up placed on the cage of the jet-propelled engine, see Fig. 1. In order to analyze of signals in band 0 to 10000 Hz was prepared the software in the environment LabView.

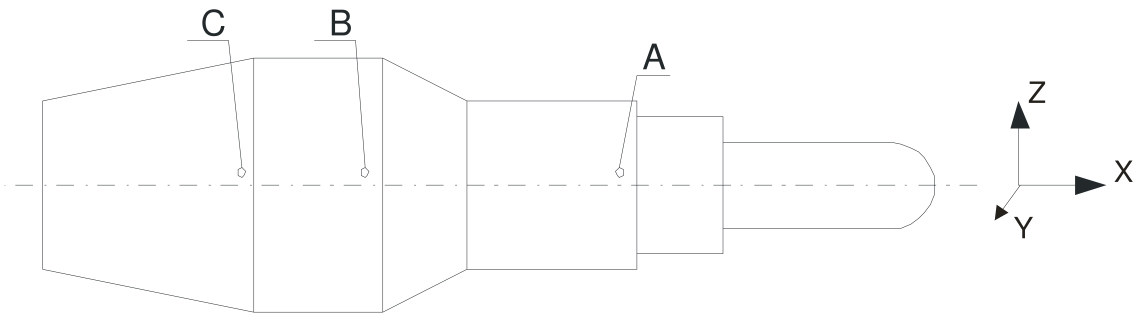


Fig. 1. Points of fixing piezoelectric vibrations sensors on the cage of the engine
Rys. 1. Punkty mocowania czujników przyspieszeń na korpusie silnika

3. REALIZATION OF THE EXPERIMENT

The experiment consists of several stages in which introduce unbalance, the damage of individual elements in order to registering the vibration answer on the cage of the jet-propelled engine. The reference point was the test of engine after the repair in the Military Aviation Depot.

Realization of the experiment was prepared according to with earlier profile of the test engine, the phantoms accelerations of the vibrations engine for the steady-state speeds of the engine were registered in result this. The next stages of test included various modification construction of engine in order to simulate damages, such as: unbalance, undercutting pin of disk, cut-out of blade, etc.

All finished stages were finished with measurement vibrations the cage engine with using the sensors of vibration in points A, B and C situated near planes: I, II and III bearing support of the engine, so as it was showed on Fig. 1.

The evaluation of the elements engine was carried out for the help in analysis of the amplitude of the frequency composition emitted vibrations.

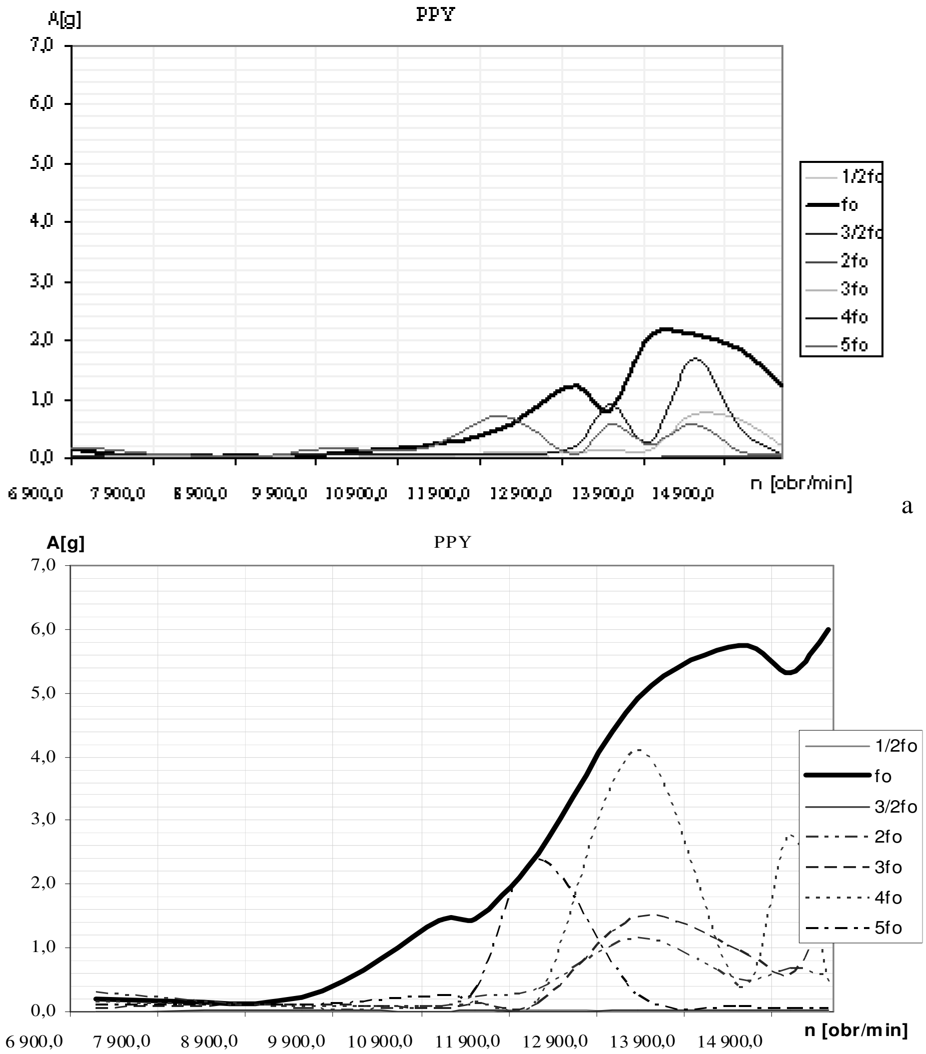
The analysis registered data of vibrations had on the aim finding possible component the phantom vibrations connected with the pronouncement of inefficiency in the various elements engine. All count treated to the rotational frequency the motive engine f_0. The lack is the gauge of the phase of the turn of the shaft engine because of the construction of the air jet-propelled engine.

4. THE DIAGNOSTIC METHOD

The measurement V_{RMS} lets qualify the only general condition of the machine, he does not define causes. In order to qualify the causes of vibrations execute their analysis by Fast Fourier Transform (FFT). Suitably prepared application in the environment LabView exchanges registered signals of vibrations on frequency courses, i.e. one gets the graphs of the amplitude of vibrations in the function of the frequency (spectrum).

By the analysis of vibrations can detect and observe what had the place during the realization of the next stages experiment:

- unbalance of rotary element introduced in the last stage, Fig. 2;



a

b

Fig. 2. Controlled unbalance the turbine 1000 [gmm]
Rys. 2. Kontrolowane niewyważenie turbiny wynoszące 1000 [gmm]

- the misalignment and/or the backlash of the shaft (indirectly), Fig. 3. The central support was marked as PSX, PSY in direction 0x and 0y axis respectively;

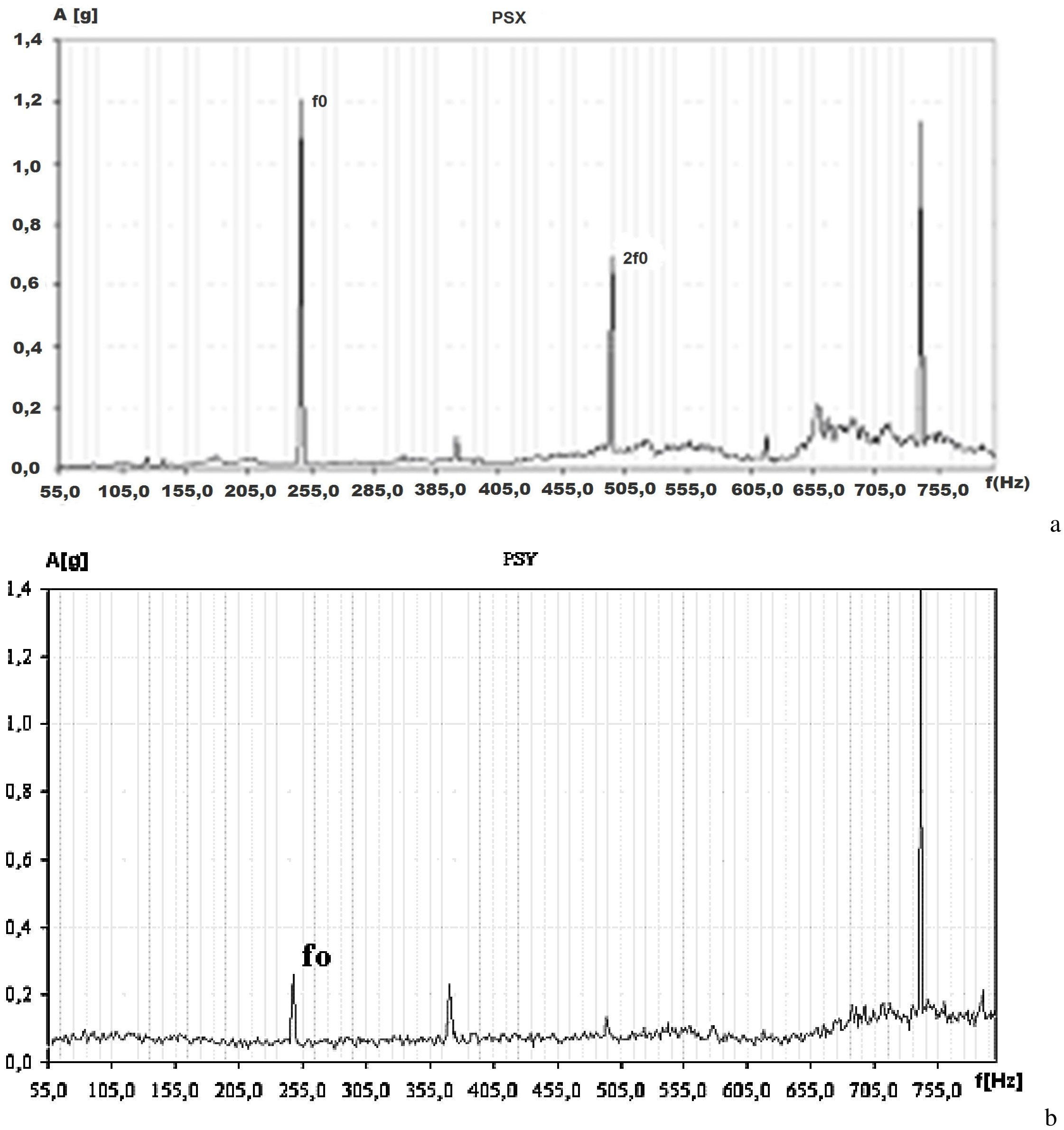


Fig. 3. Vibration spectrum showed unbalance of shaft according to the condition ($2f_{oPSX} > 0,75 * f_{oPSY}$)
Rys. 3. Widmo drgań obrazujące niewyważenie wału zgodnie z warunkiem ($2f_{oPSX} > 0,75 * f_{oPSY}$)

- subharmonics and their multiplicity, Fig. 4. The half of the value of rotary frequency and her multiplicity can indicate on backlash in the case of the bearing and the instability of bearing or his bracket;

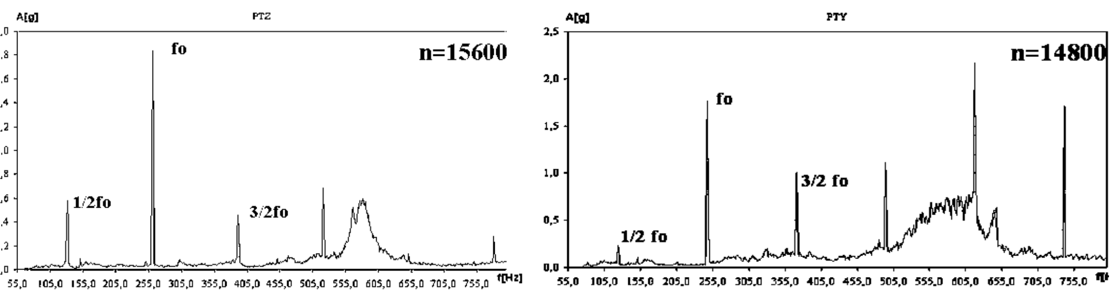


Fig. 4. Vibration spectrum with subharmonics and their multiplicity turns of shaft
Rys. 4. Widmo drgań z harmonicznymi prędkości obrotowej

- elaboration of the rolling bearing elements, Fig. 5;

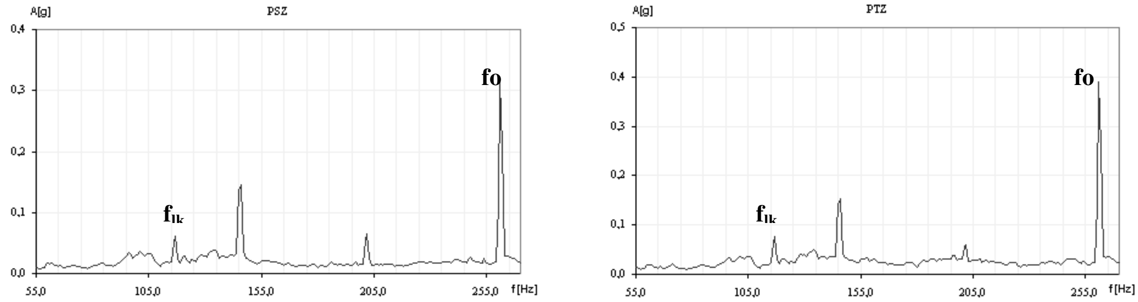


Fig. 5. Vibration spectrum with showed characterized frequency of bearing cage f_{lk} near rotary 15600 r.p.m.
Rys. 5. Widmo drgań z widoczną częstotliwością obudowy łożyska f_{lk} w pobliżu prędkości obrotowej 15600 obr/min

- inappropriate working of the mobile (whirling) elements of motor units, Fig. 6;

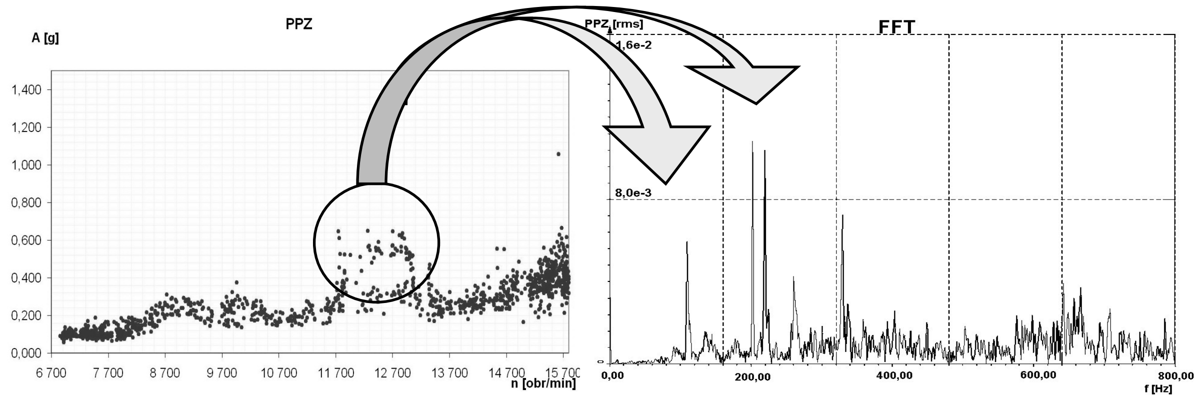


Fig. 6. Instability of the levels amplitudes of the motor units
Rys. 6. Niestabilność poziomów amplitudy skrzynki napędów agregatów

- changes in the observed resonances of structure, Fig. 7.

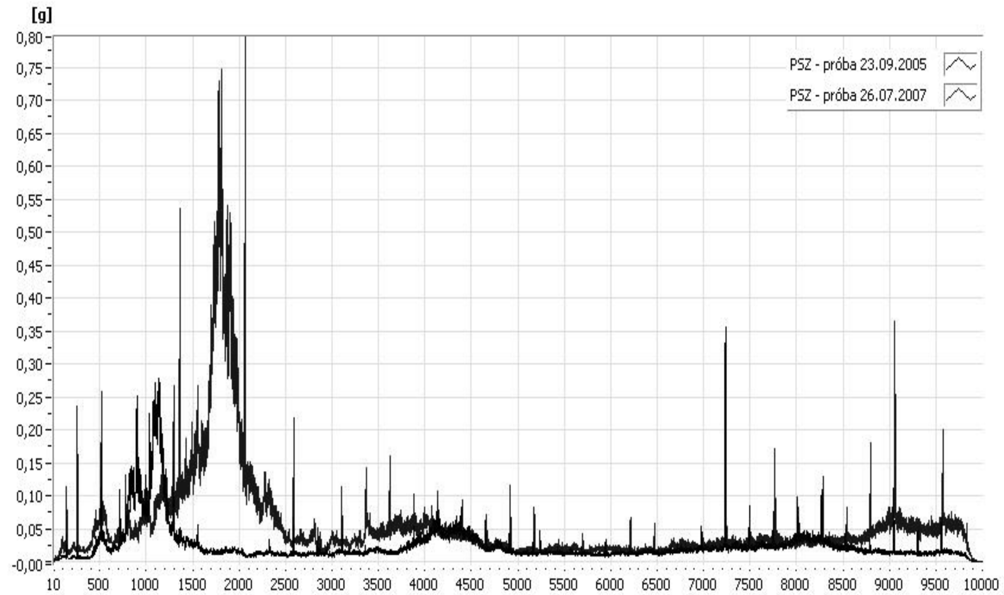


Fig. 7. Change in the observed resonances of the structure
Rys. 7. Obserwowane zmiany w rezonansie struktury silnika

5. THE ANALYSIS OF RECEIVED RESULTS

The registered signals of vibrations in all stages of the active experiment were subjected the timing and spectral analysis. Taking under the attention the rotational frequency f_0, vibrations in the band, and the amplitudes of the vibrations of the engine, without regard on the place of fixing the sensor and the direction of the measurement, they have increase tendencies. After introducing controlled unbalance (e.g. exchange, shortening blade) the value of vibrations of rotary increases crossing Technical Conditions. The measurement of the amplitude value of vibrations rotary f_0 is the simplest and quickest coefficient detecting unbalance of the rotor.

The fact that unbalance appears without regard in which part of the engine, visible changes step out on the near central bearing. The transverse axis is the optimum to the observations symptoms of damages.

Because of the introducing the multiple changes size and place of unbalance the rotor, is not possible to analyze of the character changes of the value amplitudes rotary f_0 in the function time work of the engine, and the settlement of changes setting in the elements whose technical condition is reflected through the changes of the value of the amplitudes of stripes related with the rotational frequency f_0 of the engine.

Value of the amplitudes second of the harmonic rotational speed $2{\cdot}f_0$ similarly how amplitudes rotational speed f_0 had increase tendencies in all stages of the active experiment.

Taking under the attention subharmonics rotational frequency f_0 – the half of the value of rotational frequency f_0 and her multiplicity they were seeing in the case of introducing controlled unbalances and/or the considerable damage of the movable elements of the support.

6. CONCLUSIONS

Taking under the attention the character of changes of amplitude rotational speed in next stages realization of the experiment with special damages, the conclusions were observed:

- vibrations in the band and the amplitudes of vibration engine, have increase tendencies without the place of fixing the sensor and the direction measurement. After introducing controlled unbalance (e.g. exchange, shortening blade) the value of vibrations of rotational frequency increases crossing Technical Conditions;
- the measurement of value amplitude of vibrations rotational frequency f_o is the simplest way to detecting unbalance the rotor.

The transverse and/or perpendicular axis is the optimum axis to observation of front and back support with the special regard of the axial direction.

Due to introducing many changes and place of unbalance is not possible to analyzing change of character amplitudes of vibration f_o in function time.

Analyzing rotational harmonic frequency f_o it was observed:

- the values of amplitude second harmonic rotational speed $2f_o$ and rotational speed f_o have increase tendency up to VIII stage of the test. They stay on comparable levels in the next stages;
- the growth of second harmonic rotational speed f_o in transverse directions in the relation to rotational f_o in the axial direction:
  - V stage of tests - values of amplitude of second rotational frequency f_o in range from 13500 r.p.m. to 15600 r.p.m. were to considerable high from rotational frequency f_o in the point C (axial and radial direction);
  - VII stage of tests - values of amplitude of second and third rotational frequency f_o topped the rotational frequency f_o above to the speed 12500 r.p.m. in point C (axial and radial direction). The character of changes of spectral line was unstable in the function of the growth of the rotational speed;
  - VIII stage of tests - values of amplitude of second and third rotational frequency f_o topped the rotational frequency f_o above to the speed 12500 r.p.m. in point B above to the speed

12500 r.p.m. (axial direction) and from the speed 14000 r.p.m. in the point C in axial direction. The character of changes of spectral line was unstable in the function of the growth of the rotational speed.

Above observed phenomena can provide about the unbalance of rotor and/or occurrence of the clearance.

7. FUTHER INVESTIGATIONS

Due to of using Fast Fourier Transform in order to analyze registered signals, could not unambiguously qualify simulated damages and show it in the spectrum. Therefore the next step will be use of the modern methods of the processing of signal and modal analysis, such as:

- the envelope analysis;
- the wavelet analysis;
- the modal analysis.

During the realization of different works connected with the jet-propelled engine will be planned to use of signal from the sensor vibration of blades as the gauge of phase and the place of the sensor of vibrations directly in the neighborhood of the central support of the jet-propelled engine.

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Received 04.01.2009; accepted in revised form 13.08.2009