AMAS Workshop on Nondestructive Testing of Materials
NTM'03 – (pp.149–157) – Warsaw, May 19-21, 2003.

Non-contact testing of wearing processes in airborne power generators

P. ONISZK

Military Institute of Armament Technology
Zielonka, Poland
witu@witu.mil.pl

Some main types of defects occurring in the ball bearings and diagnostics methods are discussed in the paper. Preliminary results of diagnostic tests for turbine generator ball bearings by differential laser vibrometry method are presented.

1. Introduction

It often happens to rotating elements of machinery that at long-term equipment service time some defects appear in the form of excessive vibrations. In electric power generators their bearings are believed to be the primal source of such vibrations.

The most efficient diagnostic method of vibration testing is spectral analysis of movements of monitored machinery elements. In this paper we present some main problems of ball bearing vibration frequency analysis and results of preliminary diagnostic tests by differential laser vibrometry.

2. Ball bearings characteristics and diagnostic testing methods

Ball bearings are critical mechanically loaded components power generators. Corrosion of ball track or rolling elements, seizing, spalling and roughness of ball track are some typical examples for bearing defects. They appear not only because of bearing overload or ageing process of components but also because of improper lubrication. Consequently the backlash may occur and cause dynamic disturbances and changes in vibration frequency spectrum of the generator. By measuring vibrations and determining its spectrum it is possible to derive the estimates which describe technical status of equipment. An example of such analysis is presented in Fig. 1.

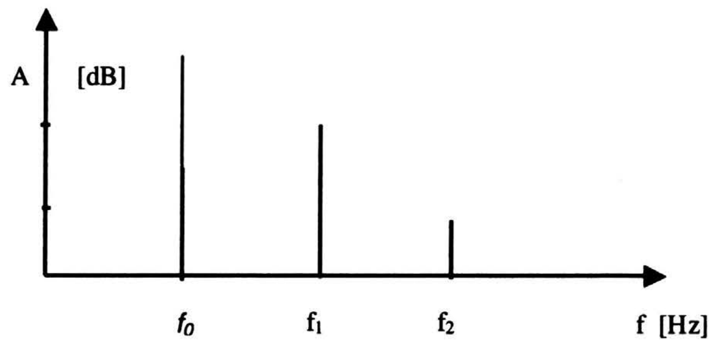

FIGURE 1. Spectral components of turbine generator vibrations as the result of unbalanced rotor – f_0, and increased loss – f_1 and f_2.

In the vibro-acoustic diagnostics of kinematic design system and especially in testing of bearings the following non-dimensional estimators are used:

- shape coefficient:

$$k = \frac{x_{\mathrm{RMS}}}{\bar{x}},$$

- peak coefficient:

$$C = \frac{\hat{x}}{x_{\mathrm{RMS}}},$$

- differential vibration coefficient:

$$R = x_0 - x_1,$$

  where: x_0 – amplitude of the principal harmonic of vibration measured in decibels, x_1 – amplitude of the first harmonic of vibration also measured in decibels;

- directional vibration load coefficient:

$$W_0 = 20 \log \frac{x_0}{x_j},$$

  where: x_0 – effective values of vibration parameters at nominal load, x_j – effective values of vibration parameters without load.

3. Description of tested turbine generator

A turbine generator constitutes a part of an onboard system of a middle range antiaircraft rocket. It is designed to power all rocket electric components during the rocket operation. It supplies a three phase voltage at 400 Hz frequency and phase voltage 115 V. It is driven by 30 MPa pressurised air via a reduction system. Pressurised air hits the blades of rotor which rotates at the rate close to 16 000 revolutions/min.

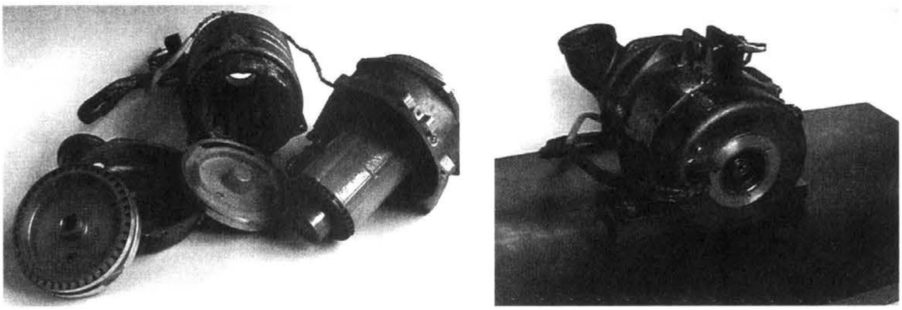

FIGURE 2. View of assembled turbine generator (right) and its components (left).

Technical characteristics of the generator are as follows:
- generated voltage: 115 V, 400 Hz,
- maximum unintermitting operation time: 4 min,
- pause between consecutive operations: min. 15 min,
- maximum operation lifetime: 1.5 hour.

4. Application of differential laser vibrometry for technical status diagnostics of ball bearings

Because of the specific character of onboard turbine generator operation the application of accelerometers or microphones is not useful because of background noises generated by depressurised air noise and sounds generated by turbine blades. Acoustic signal caused by faults occurring in bearings propagates into the shaft. It is possible to detect that signal by means of optical arrangement. A set up of this arrangement is shown in Fig. 3 and consists of:
- differential photodiode detector,
- low noise amplifier with high input resistance and controlled amplification level, power supply unit for the receiver and laser, voltmeter to control detector differential voltage,
- computer – PC 400 MHz equipped with the music Sondblaster 128 card, software to record signals with sampling rate 44 kHz, software for spectrum analysis,

- reference 4382 V accelerometer,
- Hioki 8048 signal recorder and oscilloscope.

The differential laser vibrometry is a standard method which can be defined as measuring of a differential electric signal picked up from an optical detector which is lit by a modulated laser beam reflected from a vibrating surface.

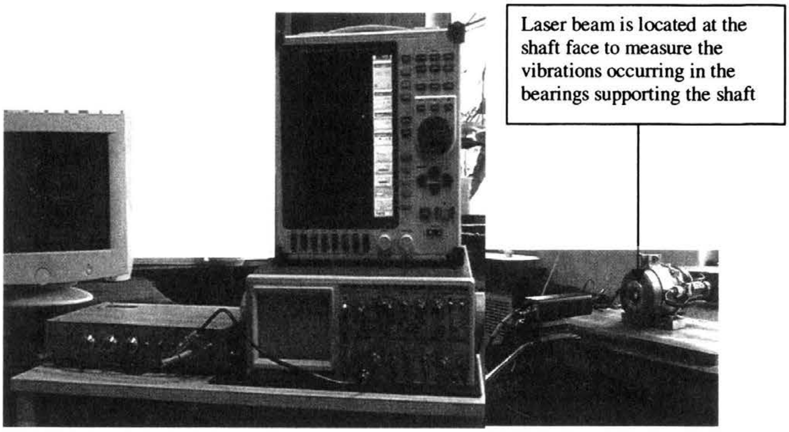

FIGURE 3. Experimantal set up. A differential laser sensor of vibrations and the generator under test are seen at the right side of the Figure.

To perform the proper calibration and accuracy the measurement consisted of several procedures listed below:

1. setting a distance to tested object,
2. preliminary evaluation of the reflected laser beam position accuracy by means of differential voltage measuring at static state,
3. precise setting of the laser beam at dynamic state on the base of differential voltage character,
4. signal amplification level adjustment,
5. digital signal registration into computer by the acoustic card,
6. Fourier spectrum analysis,
7. spectrum decomposition.

In order to secure the same measuring conditions signal was recorded each time during 10 seconds at the sampling rate 44 kHz and 8 bit resolution. The spectral characteristic of measured signal was generated 10 times of each 1 second of recording and then the results were averaged.

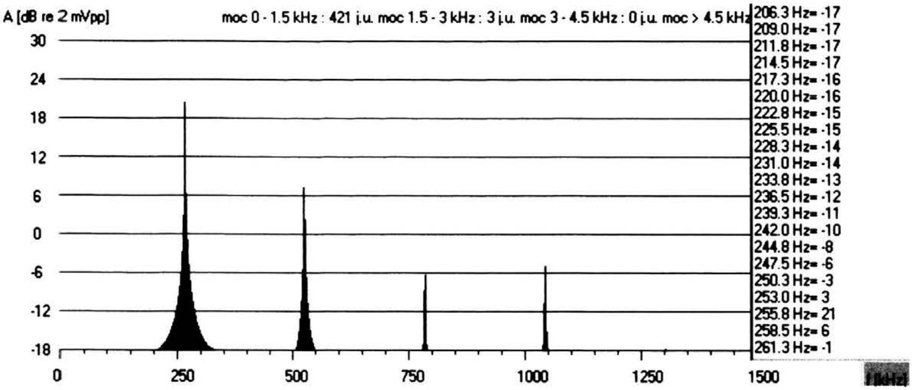

FIGURE 4. Generator #1, with no detectable faults, unloaded. First harmonic level remarkably greater than the second one.

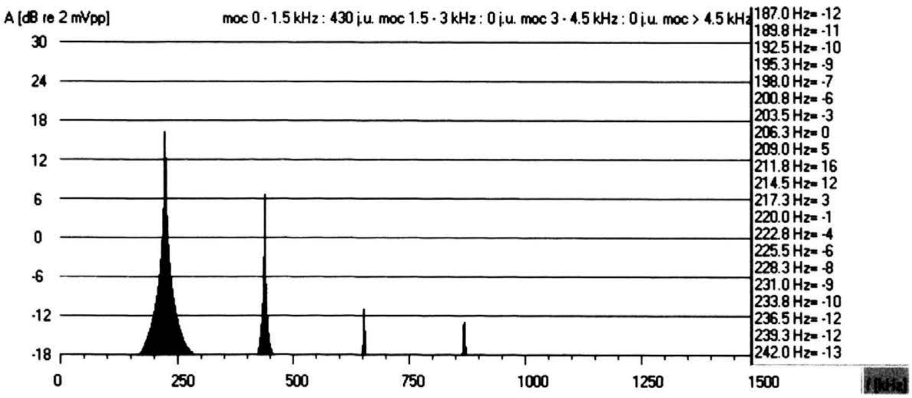

FIGURE 5. Generator #1, with no detectable faults, under load. First harmonic level remarkably greater than the second one.

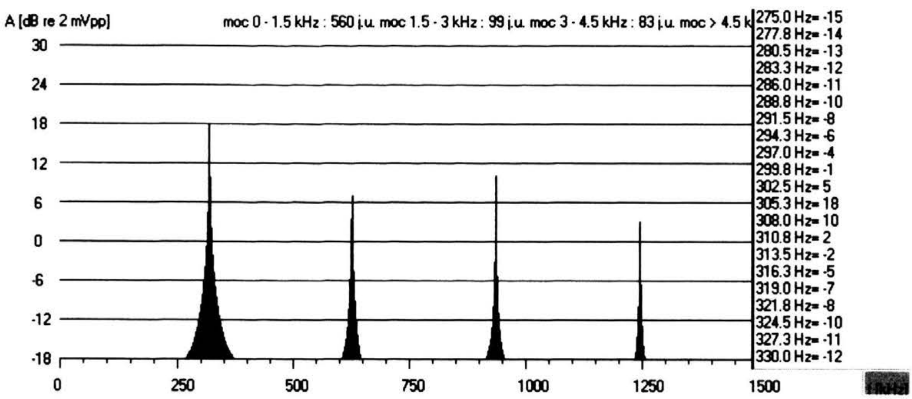

FIGURE 6. Generator #2, with no detectable faults after ca. 30 min period of operation, unloaded.

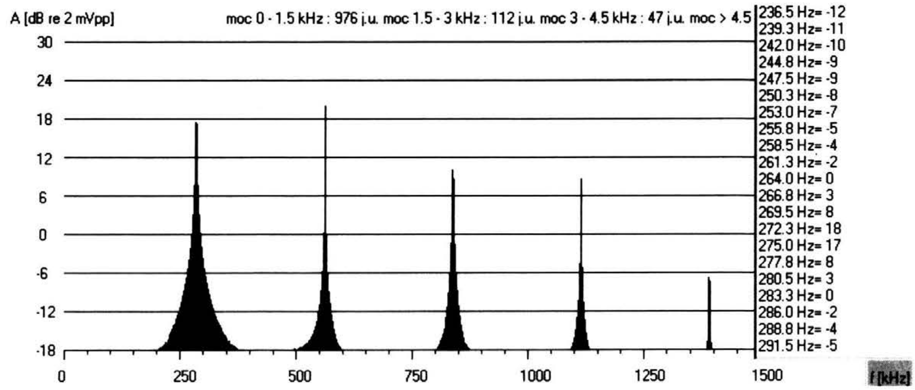

FIGURE 7. Generator #2, but after next 30 min of operation under load. First harmonic level slightly lower than the second one.

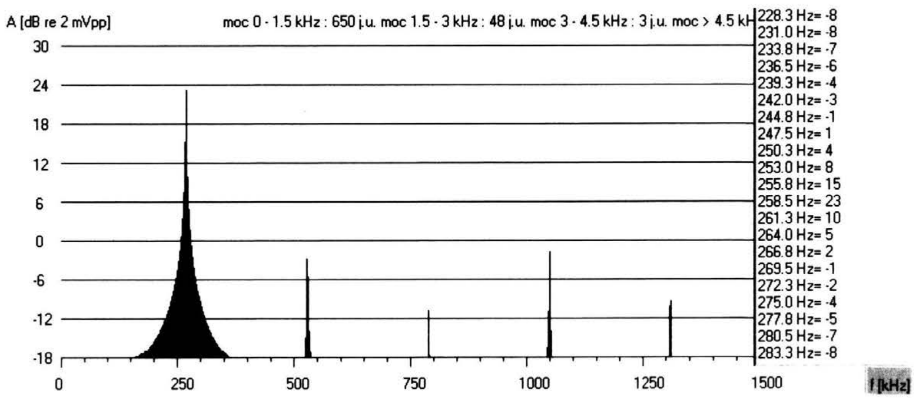

FIGURE 8. Generator #3, after short period of operation (ca. 15 min), unloaded. First harmonic remarkably higher than the second one.

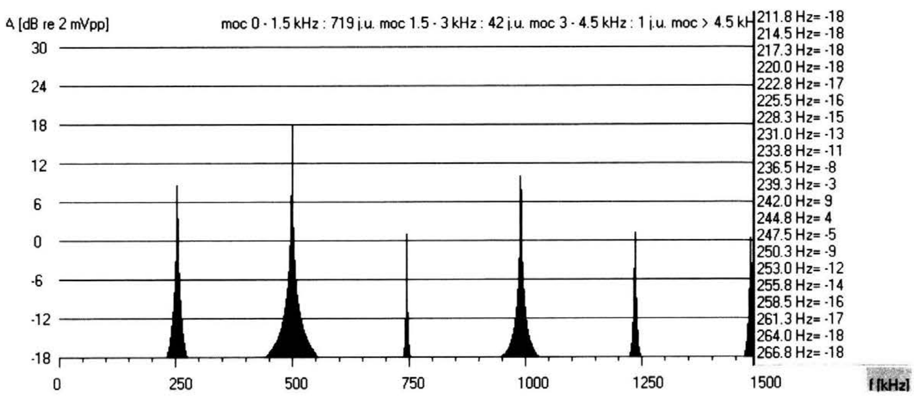

FIGURE 9. Generator #3, after 30 min of operation under load, measured loaded.

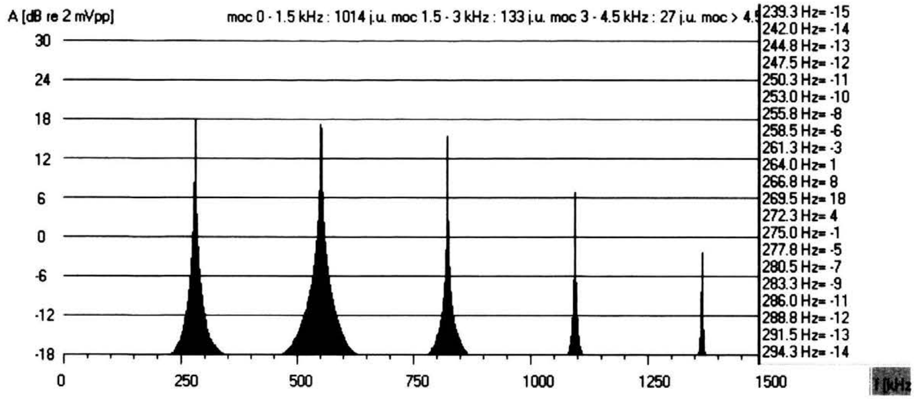

FIGURE 10. Generator #4, after 40 min of operation under load.

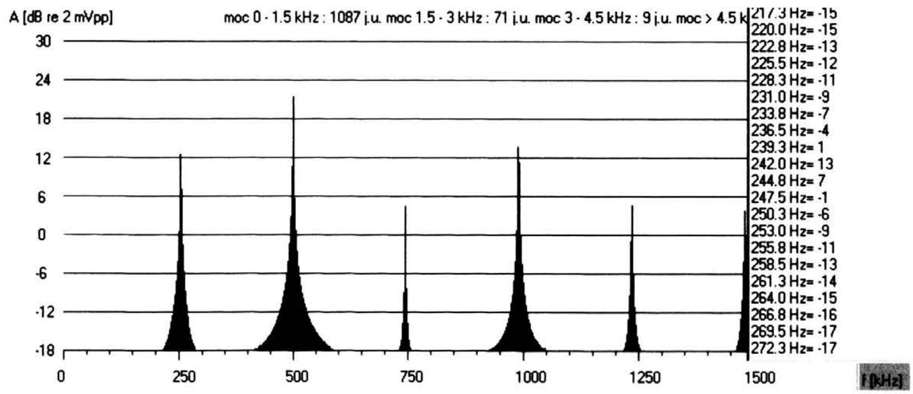

FIGURE 11. Generator #4, after 70 min of operation under load.

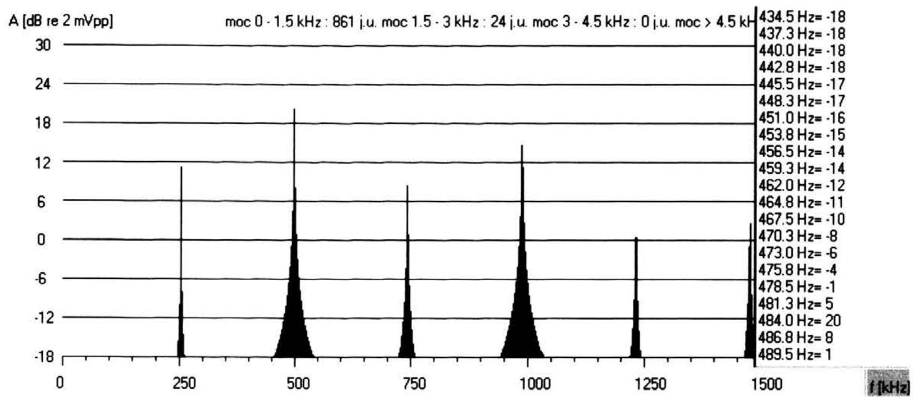

FIGURE 12. Generator #5, after 40 min of operation under load.

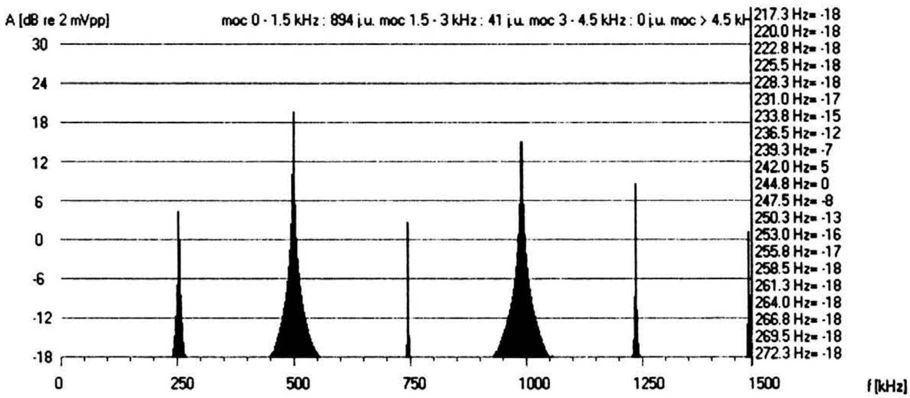

FIGURE 13. Generator #5, after 70 min of operation under load.

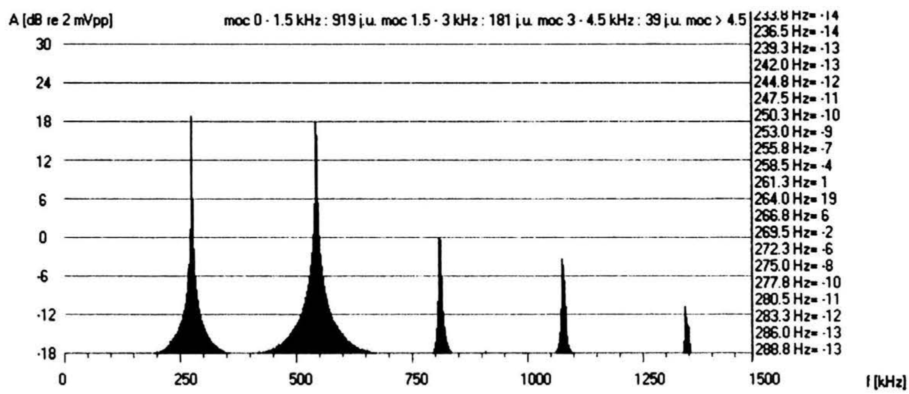

FIGURE 14. Generator #6, after 40 min of operation under load.

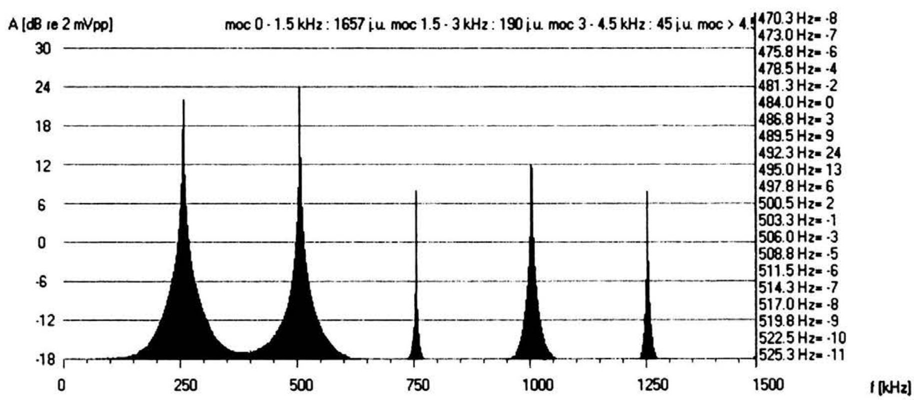

FIGURE 15. Generator #6, after 70 min of operation under load.

5. Test results

Results of measurements done in six turbine generators are presented in Figs. 4–15 and are summarised in Table 1.

TABLE 1. Experimental results of tests made on six generators.

Generator #	Differential vibration coefficient R	
	before operation	after 30 min of operation
1	14	10
2	11	-2
3	18	-9
4	3	-9
5	-9	-15
6	1	-2

6. Conclusions

Presented results indicate that the strongest effects of wear of bearing appeared in turbines #3 and #5. These bearings have reached also the highest temperatures, being the result of improper lubricating and excessive loosing.

It was assumed that the change of the differential vibration coefficient from positive to negative values indicates that defective process in the bearing appear.

The differential laser vibrometry method confirmed its efficiency for determination of quality of airborne power generator.

References

1. R. ŁĄCZKOWSKI, *Wibroakustyka maszyn i urządzeń*, WNT, 1983.
2. C. CEMPEL, *Wibroakustyka stosowana*, PWN, 1989.
3. W. KUROWSKI, *Dyskretne widmo Fouriera w diagnostyce wibroakustycznej*, Politechnika Białostocka, 1997.
4. J. DWOJAK J., M. Rzepiela, *Diagnostyka drganiowa stanu maszyn i urządzeń*, Biuro Gamma, 1999.
5. T. KUCHARSKI, *System pomiaru drgań mechanicznych*, WNT, 2002.