Modal testing circuit board assembly of an electronic apparatus by laser vibrometry

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Abstract. The operating capacity and service life of printed circuit boards in various electronic equipment and devices depends on their ability to resist vibroacoustic loads, including vibration and acoustic noises. In this paper, non-contact laser vibrometry has been applied to perform the modal analysis of a circuit board assembly in order to identify its vulnerable spots and to find solutions to protect the assembly from external vibroacoustic loads. A broadband periodic chirp signal was used to excite vibration, which enabled a rapid generation of results. The paper provides data on eigenfrequencies, vibration velocity fields, and vibration displacement profiles. Frequency ranges have been determined in which eigenfrequencies with the highest vibration amplification lie. The obtained data can be used to develop a quality control technique for printed circuit boards and to optimize their construction as early as the design stage.

1. Introduction

Modern electronics equipment during service and transportation is often subjected to dynamic loads, such as vibrations, shocks and overloads, acoustic noises. These loads can disturb the normal operation mode of equipment, initiate damage of its components, and lead to failure. In many cases, failure of the components and parts of electronic circuit boards widely used in various industries is induced by vibroacoustic loads from various operating mechanisms and devices. Vibroacoustic frequencies can coincide with vibration eigenfrequencies of circuit board components, causing resonance and subsequent failure. For example, aerospace equipment experiences vibratory loads while moving in the atmosphere with high velocities and overcoming environmental resistance. Additionally, jet noises and airflow pulsations give rise to variable pressures of 170–190 dB in aircraft skin at the vibration frequency 0–5 kHz. As a result, the vibration amplitude level can reach 20g and higher, which leads to resonance phenomena in electronic circuit boards [1–3]. Resonance makes the overloads acting on the electronic components mounted on circuit boards to increase drastically [3, 4].

Vibration-induced failure can be avoided by determining eigenfrequencies and eigenvibrations of components and by taking them into account in further design [1, 5, 6]. Data on vibration modes, vibration decrement and other modal characteristics are also necessary for the verification of finite element models used in the development of electronic systems [7] and in the computer design of new materials [8]. With knowledge of eigenvibrations and vibration velocities, it is possible to calculate the dynamic stress field distribution in bench testing as well as under real operation conditions of electronic equipment. These data can be obtained using laser vibrometry methods [9].

Laser vibrometry is a modern, qualitatively new technique of measuring mechanical vibration parameters of objects. Unique physical characteristics of laser methods largely contribute to their advantages. These are the possibility of distant, non-contact vibration measurement and the absence of effect on the resonance properties of objects; the possibility of vibration measurement in different points of an object in human hazardous environments (chemically aggressive, high temperature, radiation, etc.). Today laser vibrometry is extensively applied in dynamic testing of various printed circuit boards. Quality control approaches are developed for fault inspection of electronic equipment and its components and for optimization of circuit board arrangement [3, 6, 7, 9-11].

This paper reports the experimental data obtained using a three-axis scanning laser vibrometer, namely, eigenvibrations and eigenfrequencies of a circuit board assembly.

2. Equipment

A three-axis scanning laser Doppler vibrometer was used to measure the vibration velocity characteristics and to perform modal and harmonic analysis.

A scanning laser vibrometer PSV-500 (Polytec Scanning Vibrometer) measures three orthogonal components of vibration velocity based on the principle of laser interferometry (a laser beam reflected from the moving surface interferes with a reference beam). Since the measurement technique is non-contact, the modal characteristics of objects excited by vibration remain unchanged in the experiment and the obtained vibration modes are undistorted, which cannot be achieved in measurements with the use of mounted detectors.

Modal tests require that the boundary conditions, as a rule these are the conditions of workpiece mounting, must be as close to real conditions as possible. Another requirement is an adequate and physically justified choice of the exciting signal and the exciter for the vibrational loading of the workpiece. In this paper, the exciter was a TMS 2075E vibration shaker driven by the internal generator of the vibrometer. A broadband periodic chirp signal was used. Frequency spectral analysis was performed within the range from 0 to 4 kHz.

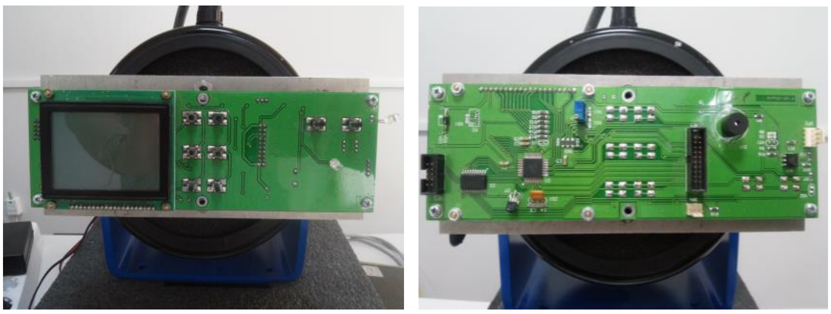
3. Modal testing of a printed circuit board assembly of an electronic apparatus

The performance of modal tests and the processing of obtained vibration velocity fields of electronic equipment units and components include the following tasks:

- to perform modal testing of electronic equipment units and components;
- to determine the principal modes of circuit board components and parts, and of the whole circuit board;
- to provide efficient operation of electronic equipment systems and components through the modification of the electronic equipment construction and its optimization based on modal test data.

Let us consider modal test performance by the example of a printed circuit board assembly.

The tested board was fixed by hex pillars and screws to a solid steel plate in position 1 and position 2 (Figure 1a, b). The steel plate was screwed to the vibration shaker.



a) b)

Figure 1. View of the board screwed to the shaker in position 1 (a) and 2 (b)

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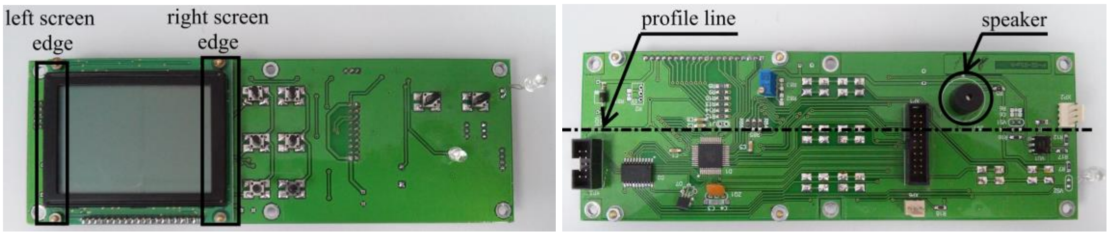
The first few vibration modes are always of particular interest. Subsequent modes are shown to illustrate the capabilities of the apparatus.

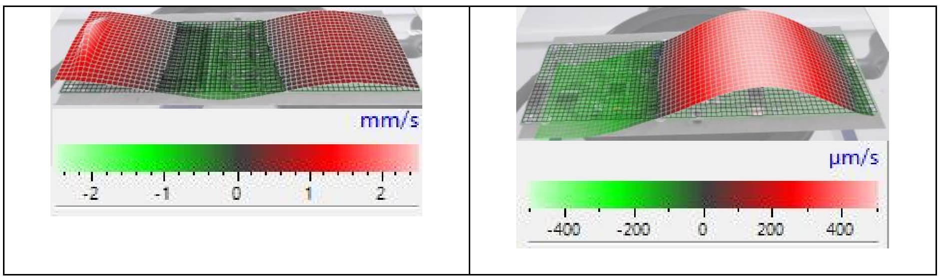
The results of laser Doppler vibrometry has shown that different vibration modes (see Figures 3-10) are observed simultaneously on the both sides of the circuit board fixed in position 1 and 2 (Figure 1a, b). It was revealed that different circuit board regions experience maximum displacement in different vibration modes, with particular board components being in these regions. These circuit board components also lie in the regions of maximum vibration velocities, and arising sign-alternating loads can destroy solder joints or component mountings due to fatigue damage accumulation. For example, testing in position 1 within the resonance frequency range 550–765 Hz (mode 3–6) showed that the vibration velocity fields and their profile in the left part of the board are significantly different from those in the right part; there is an antinode at one of the fixed edges (left) of the liquid crystal screen for which the detected vibration velocity was 0.2–2 mm/s. The right edge of the fixed screen had the maximum displacement on modes 13–16 (2399, 2606, 2713 and 2936 Hz, respectively), accelerating up to vibration velocities of 5–50 μm/s. It should be noted that the both screen edges are in resonance on modes 13 and 14. In so doing, the acoustic radiator (speaker) on the back side of the board (position 2) which is near the connector and vibrates with a velocity of 5–20 μm/s enters into resonance (modes 17–19; 2625, 2860 and 3103 Hz). Modes 19, 20 and 22 demonstrate that there is an antinode in the entire circuit board region behind the liquid crystal screen (3103, 3236 and 3760 Hz, respectively) vibrating with a velocity of 10–50 μm/s.

Thus, the screen mountings (vibration velocity up to 2 mm/s) and the speaker (vibration velocity up to 20 μm/s) are most vulnerable to vibration. Consequently, if the apparatus operates in the aforementioned working frequency range, the circuit board construction must be changed (Figures 2a, b). Attention must also be paid to the arrangement of other components: their mountings must not be in regions with considerably different vibration velocities, especially where the vibration velocity changes its sign or direction (see Figure 3-10).



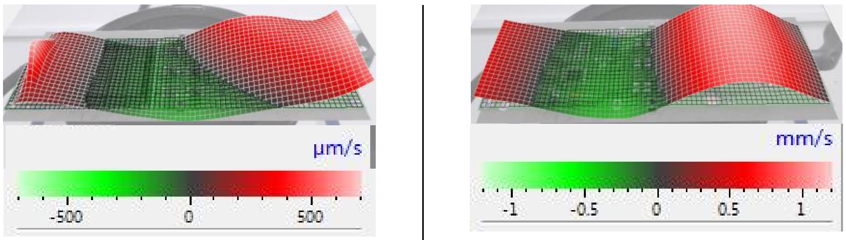
a) b)

Figure 2. Fixed screen edges entering into resonance (a) and speaker entering into resonance (b)



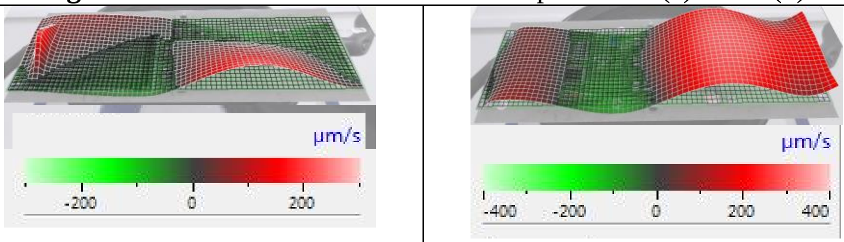
a) Frequency 550.5 Hz b) Frequency 347.3 Hz

Figure 3. View of the mode 3 of board in position 1 (a) and 2 (b)



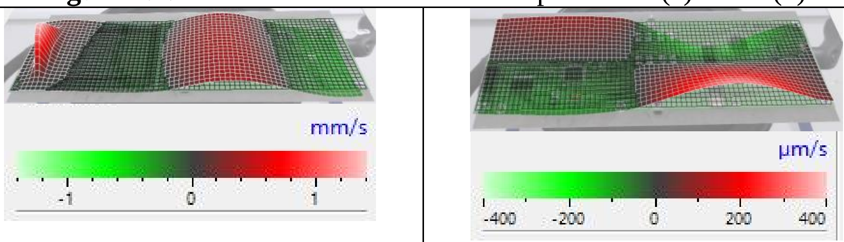
a) Frequency 620.6 Hz b) Frequency 431.9 Hz

Figure 4. View of the mode 4 of board in position 1 (a) and 2 (b)



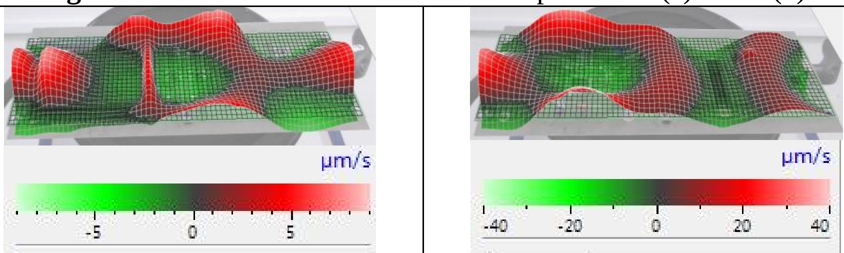
a) Frequency 731.8 Hz b) Frequency 570.3 Hz

Figure 5. View of the mode 5 of board in position 1 (a) and 2 (b)



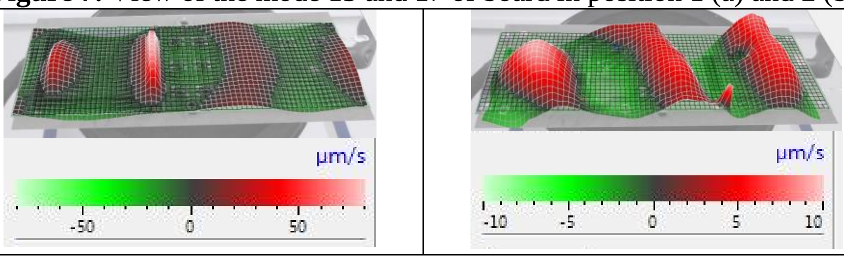
a) Frequency 765 Hz b) Frequency 695.5 Hz

Figure 6. View of the mode 6 of board in position 1 (a) and 2 (b)



a) Frequency 2399.7 Hz b) Frequency 2625.1 Hz

Figure 7. View of the mode 13 and 17 of board in position 1 (a) and 2 (b)



a) Frequency 2606.5 Hz b) Frequency 3103.1 Hz

Figure 8. View of the mode 14 and 19 of board in position 1 (a) and 2 (b)

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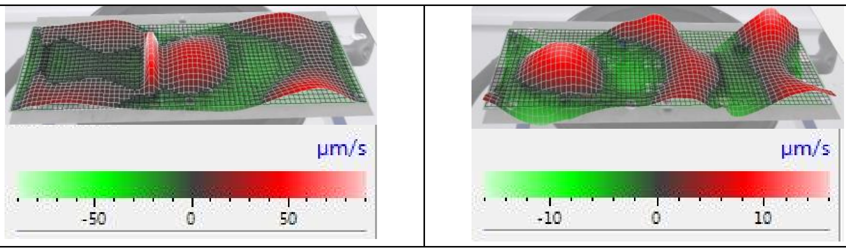
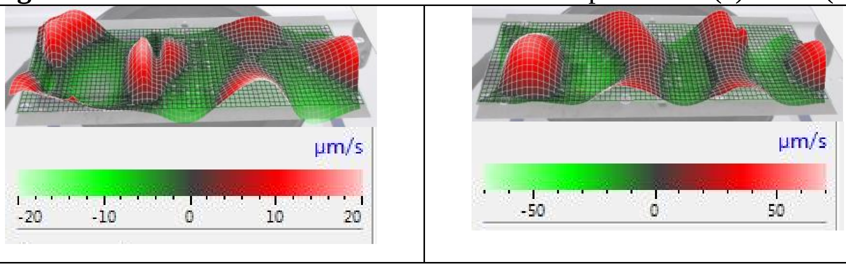


a) Frequency 2713.8 Hz b) Frequency 3236.9 Hz

Figure 9. View of the mode 15 and 20 of board in position 1 (a) and 2 (b)



a) Frequency 2936.5 Hz b) Frequency 3760 Hz

Figure 10. View of the mode 16 and 22 of board in position 1 (a) and 2 (b)

Vibration displacement amplitude profiles were obtained for vibration modes 1–6 (see Figures 11-16). The highest amplitude reaches 2.5–2.7 µm for the first two modes. The highest amplitude for the first mode is achieved in position 1, and for the second—in position 2. Amplitudes for other vibration modes do not exceed 0.7 µm. These data were obtained at an average shaker speed of 0.13 mm/s. It was found for the first vibration mode that the maximum vibration velocity on the circuit board at the given shaker speed is 1.16 mm/s. Correspondingly, the vibration amplitude is amplified by a factor of 9 on this mode (frequency 131.9 Hz), which is significant. For other vibration modes a 3-4-fold vibration amplification was detected.

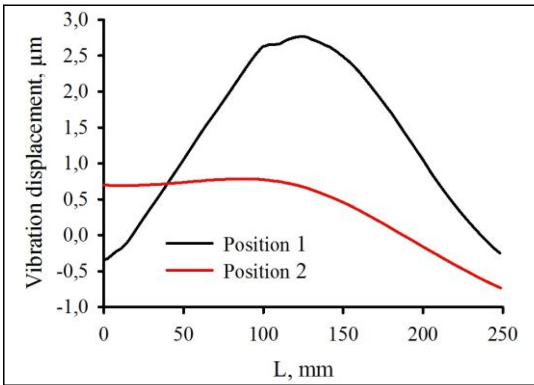


Figure 11. Profiles of natural mode 1 vibration displacement (position 1 – 131.9 Hz, position 2 – 109.4 Hz)

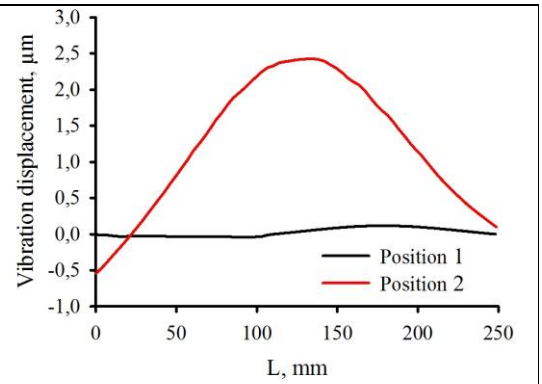


Figure 12. Profiles of natural mode 2 vibration displacement (position 1 – 409.4 Hz, position 2 – 131.9 Hz)

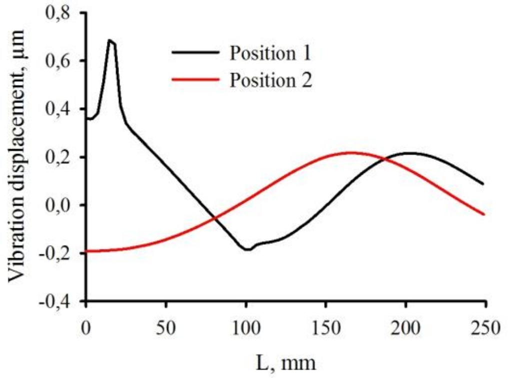


Figure 13. Profiles of natural mode 3 vibration displacement (position 1 – 550.5 Hz, position 2 – 347.3 Hz)

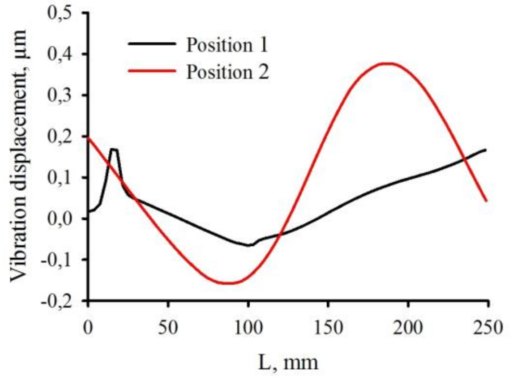


Figure 14. Profiles of natural mode 4 vibration displacement (position 1 – 620.6 Hz, position 2 – 431.9 Hz)

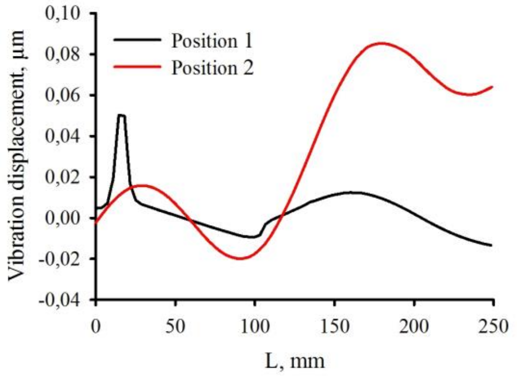


Figure 15. Profiles of natural mode 5 vibration displacement (position 1 – 731.8 Hz, position 2 – 570.3 Hz)

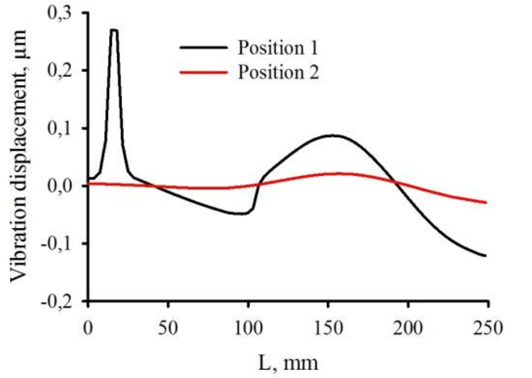
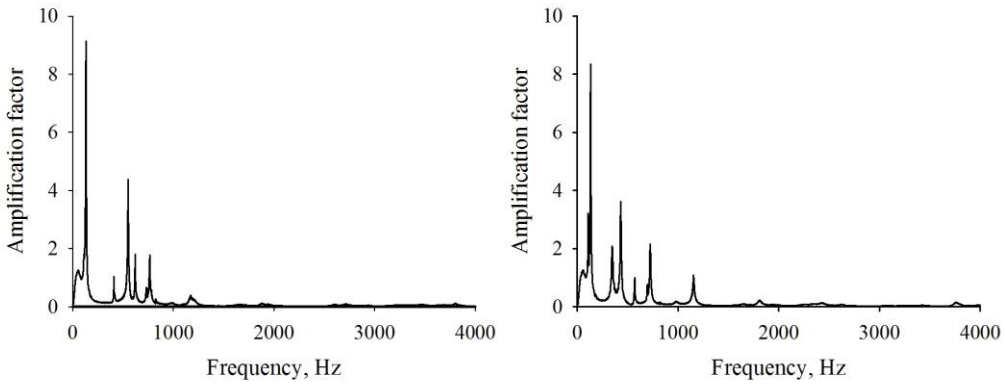


Figure 16. Profiles of natural mode 6 vibration displacement (position 1 – 765 Hz, position 2 – 695.5 Hz)

Data on the amplification factor were obtained for the frequency range 0–4 kHz (Figure 17 a, b). As one can see, frequencies of up to 1 kHz are most dangerous; vibration amplitudes within this range increase many-fold. The eigenvibrations whose profiles exhibit abrupt changes in vibration displacements also fall within this range (see Figures 11-16). In the remaining frequency range from 1 kHz to 4 кHz no many-fold amplitude increase is observed.



a) b)

Figure 17. Vibration amplification factor for the circuit board fixed in position 1 (a) and 2 (b)

4. Conclusion

The eigenvibrations obtained in circuit board scanning on both sides are generally similar. The difference in the two experiments is mostly due to the contribution of individual components mounted on different sides of the board, such as a liquid crystal screen and a speaker. The chosen circuit board design and assembly provide strongly different vibration velocity amplitudes from 5 μm/s to 2 mm/s at the frequencies 550–760 Hz (left screen edge), 2399–2936 Hz (right screen edge) and 2625–3103 Hz (board region behind the screen). The most dangerous factors are the eigenvibrations that correspond to abrupt amplitude changes in profiles and a many-fold vibration amplitude increase with respect to the shaker vibrations. Such eigenvibrations are observed in the range up to 1 kHz. In order to improve the device reliability, it is recommended either to avoid vibrations with the mentioned frequency ranges or to modify the circuit board design and component arrangement so that to shift dangerous frequencies beyond the working frequency range. No critical amplification of vibrations is observed in the range 1–4 kHz.

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