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A new vibration measurement procedure for on-line quality control of electronic devices

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Abstract: In this paper the problem of experimentally testing the mechanical reliability of electronic components for quality control is approached. In general, many tests are performed on electronic devices (personal computers, power supply units, lamps, etc.), according to the relevant international standards (IEC), in order to verify their resistance to shock and vibrations, but these are mainly "go no-go" experiments, performed on few samples taken from the production batches.
The idea here proposed is to improve the efficiency of these tests by using electro-optic techniques for the measurement of the vibration behaviour of the components under known excitation. This would allow the on-line testing of a high percentage of the production and would be useful to give important feedback to the design process.
Scanning laser Doppler vibrometry seems to be a valuable solution for this problem, thanks to its capabilities of measuring several spatially-defined points on a vibrating object with reduced testing time for on-line application, with high sensitivity and accuracy, non-intrusivity and with any kind of excitation signal. Experimental tests are performed on a power supply: the results show the effectiveness of the proposed approach. The metrological problems connected with the on-line implementation are also discussed.

Keywords: Vibration measurement, quality control, electronic components, laser vibrometry

1. Introduction

In Europe the disappearing of the commercial frontiers, determined by the European Community, has led to the development of certifying systems, with the aim of making the free circulation of products and services easier within the common market. The technologic evolution and the entry of the companies in a bigger international market have moved, therefore, the competition on the "Quality" level.

In the industry of electronic systems and components, several are the quality control procedures required by the European and the International standards. Some of them are related to verify the capabilities of products to resist to dynamic excitations, as vibrations or shock (e.g. [1]). These standards specify methods of test applicable to components or equipment which, during transportation or in service, may be subjected to conditions involving vibrations (e.g. harmonic excitations due to rotating, pulsating or oscillating forces, such as those generated in ships, aircraft, land vehicles, etc.). The tests consist in subjecting the specimen to known vibration (sinusoidal, impulsive, etc.) over a given frequency range for a certain period of time. In particular cases, an investigation aiming at determining critical frequencies of the specimen may be specified. The response shall indicate whether the specimen still works after having been submitted to vibration.

These tests have mainly a routinely character: even if they produce referring parameters to individuate the production quality, the data are not always complete and useful to give any feedback for the design phase. Tests able to produce detailed information (e.g. which the most critical components are and which their vibration behaviour is) are still carried out only in laboratories, due to the difficulties in the execution and to the time required for data processing.

In this field, the application of the electro-optic techniques for vibration measurement can be of great help. In fact, these techniques allow to determine the vibra-

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tion behaviour of the single components with reduced testing time, non-intrusivity and with high sensitivity and accuracy.

In the electronic industry, the growing interest towards the application of non-contact sensors for vibration problems is witnessed by some studies presented in literature. For example, in [2] laser vibrometry is utilised to investigate the effect of platter resonances in hard disks which, excited by the rotational velocity, produce negative effects on the quality of data registration. Other studies on disk drive dynamics are presented in [3]. In [4] a three axis modal analysis of a magnet head gimbal assembly is performed using a laser vibrometer and an in plane vibrometer.

However, most of these works are related to laboratory applications, even if at present the electro-optic measurement techniques offer large potentials for exporting these investigation procedures directly on the production lines.

The idea of the present paper is to propose the application of non-contact sensors also for on-line quality control in vibration tests of electronic devices, in such a way as to satisfy the increasing demand for quality. Even if these sensors are still in some cases expensive and complicated, the recent development in the relevant technologies are bringing them to be accessible also for industrial use, thank to their improved reliability and handiness. For example, new compact laser vibrometers have been recently introduced in the market, with high performances and very reduced dimensions. These are particularly suitable for on-line and in-field applications. Other examples of innovative sensors to be considered for these uses could be the followings:

– low cost self-mixing vibrometers [5];
– interferometers in integrated optics [6];
– micro-scanning systems [7];
– fibre-optics systems [8];
– other non-Doppler sensors (e.g. triangulation) [9].

The electronic device considered in the present work is a power supply. Actually, for this kind of device, quality control tests are performed off-line according to the actual standards. Vibrating test-benches are employed, in order to verify if the products are able to perform their function under a fixed acceleration level of vibration. A deeper study of the dynamic properties of the different installed components may define if the defects of the final products are due to errors in the design phase or to a not accurate assembly in the fabrication process.

The proposal of this work is to use the Scanning Laser Doppler Vibrometry (SLDV) [10,11] to perform on-line vibration quality tests. The results can be useful not only to make the tests more accurate and repeatable, but also for other several purposes, e.g. to verify the project choices regarding the lay-out of the different components or to perform a deeper statistic analysis of the anomalies to highlight the critic rings in the production chain.

2. Case study: the object and the experimental procedure

The case study analysed in this work is a power supply PS 138 (Fig. 1) produced by ROAL Electronics. This device has 9 outputs, a power of 600 W and is usually employed for network servers of medium-high quality.

The external dimensions of the object are 23 cm $\times$ 20 cm $\times$ 15 cm and its weight is about 5 kg. It is made by a metal box containing electronics components and boards fixed on the metal shield. The metal box is composed of two separate groups (Fig. 1), which are assembled together in the final product.

In the performed tests the two parts are separated, in order to obtain the optical access to the electronics for the laser beam of the measurement system, and fixed on the shaker. In this feasibility study, the aim is to verify the capabilities of the measurement chain in performing the required tests.

A scheme of the experimental set-up is reported in Fig. 2. The electro-dynamic exciter (RMS SW1200) is capable of applying, to the electronic device under test, a force up to 500 N between 2 Hz and 5 kHz.

Each part of the power supply was positioned and fixed on the aluminium vibrating board of the shaker, in such a way as to excite all the components along the three axes (one test for each axis). The vibration map is then measured using a Scanning Laser Doppler Vibrometer. The input level of acceleration was controlled by a piezoelectric accelerometer mounted on the aluminium table of the shaker. This signal is utilised also as phase reference for the mode shape reconstruction.

In order to individuate the resonance frequencies of the different components, the tests were firstly performed using white noise excitation in a frequency range up to 1000 Hz. Once the resonances have been found, the tests can be repeated giving a sinusoidal vibration at these frequencies, in such a way as to extract well-defined modes of vibrations.

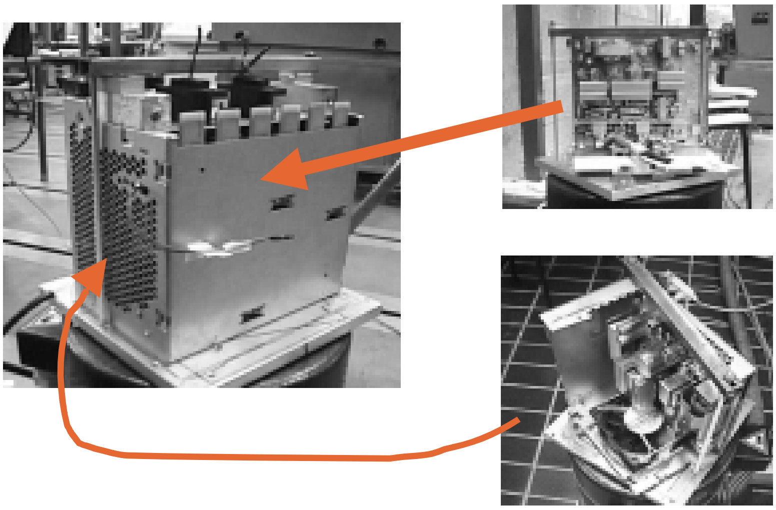

Fig. 1. The tested power supply.

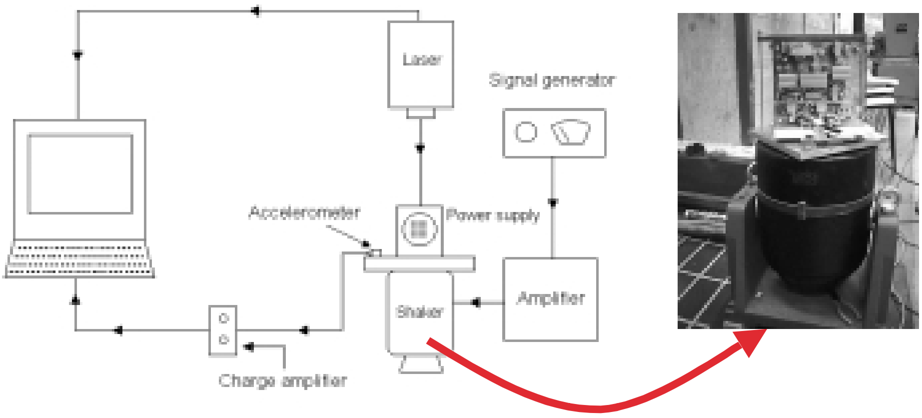

Fig. 2. The experimental set-up.

3. Analysis of results

The results of the tests performed can be described in terms of frequency spectra for each component and of vibration maps for the whole power supply. In practice, once the vibration is measured in each point of the defined grid, it is possible to detect the main resonances and, eventually, to extract the mode shapes at those frequencies.

Examples of results from the performed tests are shown in Fig. 3 (resonance of the capacitor) and Fig. 4 (resonance of the diode bridge). In these cases, a random signal was used to drive the shaker.

In the vibration maps, the distribution of acceleration magnitude is reported superimposed to the image of the object, which is taken by the CCD camera positioned in the vibrometer head. This allows to easily find the correlation between the detected resonance and the component. The results are of immediate interpretation, even for a non-expert operator.

The frequency spectra are measured on the resonating elements: the peak of vibration is clearly put in evidence and the acceleration magnitude identified.

Results are reported in acceleration scale (the laser vibrometry measures a velocity signal, which is then converted in acceleration), since this is the measurement unit used to indicate the limits of vibrations in all the relevant International Standards for vibration testing of electronic devices (e.g. [1]), where the requirement is to perform tests using accelerometers. It is clear that, in this case, the use of accelerometers or of other contacting sensors is not feasible, in particular thinking to the on-line application.

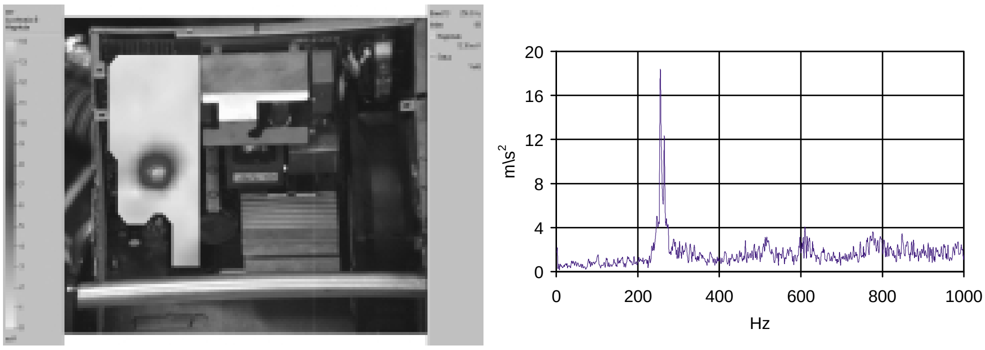

Fig. 3. Resonance of the capacitor at 255 Hz: acceleration vibration map and relative frequency spectrum.

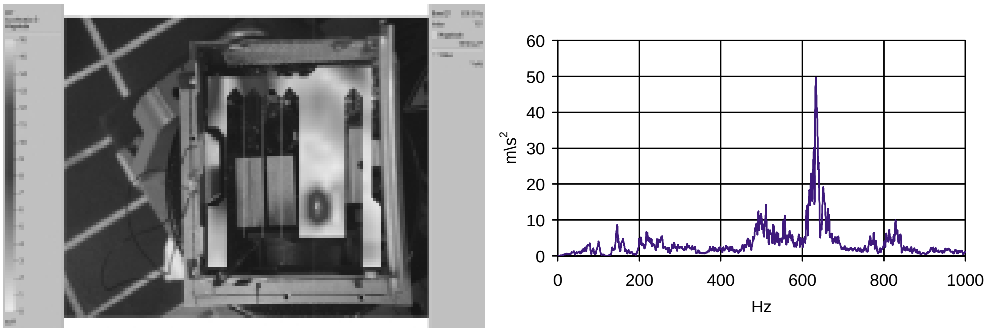

Fig. 4. Resonance of the diode bridge at 635 Hz: acceleration vibration map and relative frequency spectrum.

In order to perform the measurements with the laser vibrometer, it is necessary to have optical accessibility to the components, requiring, as previously shown, that the two parts of the power supply are separately tested (Fig. 1). This means that the constraint conditions for the elements inside the box are different in the tests and in the real operating conditions.

Some tests were performed in order to quantify the influence of this condition, with the aim of validating the proposed measurement procedure.

In these tests, an accelerometer with mass of 0.65 g was positioned on a radiator inside the power supply, the two parts were assembled and the whole unit was put in vibration on the shaker driven by a white noise signal.

The achieved results were then compared with those measured by the laser vibrometry on the same point and with the same excitation signal, but with the two parts separated. Results are shown in Fig. 5.

It is possible to note that the two spectra are very similar, even if some differences can be highlighted: in the laser results, the amplitude of vibration is larger (about the double) and a higher modal density can be found.

Considering that the mass of the accelerometer is lower than 1/10 of the mass of the radiator, the intrusivity can be considered as negligible. Therefore, the differences are mainly due to the different constraint conditions: when the two parts are assembled, the mobility of the components is reduced and some of the minor modes are suppressed. In other words, the system becomes more "compact", also because of the increased stiffness of the external box that now is closed.

However, the two conditions can be suitably correlated: the main resonance frequencies are the same and the amplitudes of vibration can be compared using a "scaling factor", that can be easily experimentally determined.

This allows to conclude that the test methodology proposed is capable of determining the vibration behaviour of the analysed power supply, being representative also of the real working conditions.

4. Design of the on-line application

For the considered power supplies the standards do not impose a level of allowed vibration for each component, but they require only that the device is subjected

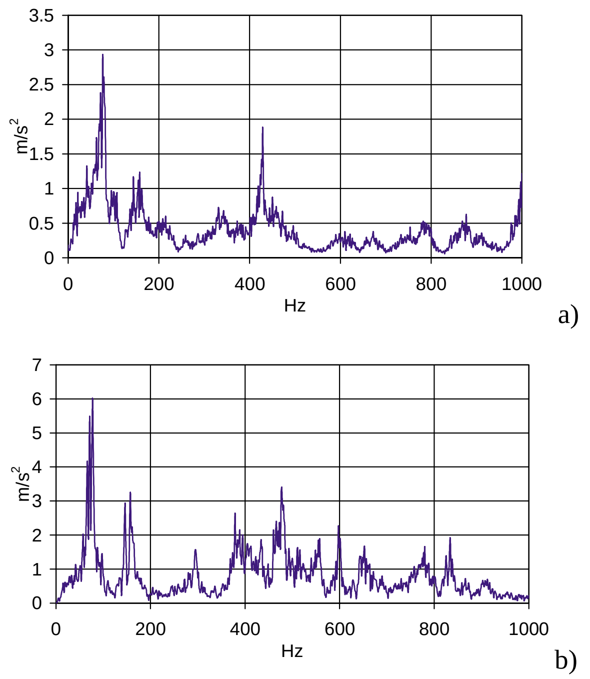

Fig. 5. Comparison between the signals of the accelerometer (a), positioned on a radiator with the two parts assembled, and of the laser sensor (b) measuring on the same component with the two parts separated.

to prescribed cycles of vibrations and that it is still correctly functioning at the end of the test. This analysis can not be performed on-line on the whole production, since it may be destructive and time consuming.

Therefore, the idea is that, in order to design a procedure for on-line quality control based on the proposed method, some correlation should be found between the vibration behaviour of the object under known excitation and the mechanical reliability determined through the "go no-go" tests indicated by the standards. A significant sample of "good" and "defected" units should be considered: the "defected" sample should contains examples of products with all the most typical and frequent defects, in such a way as to create a data-base representative of the real production. A vibration frequency spectrum should be measured by the scanning laser for each component of the whole sample and then, for each component, resonance frequencies and amplitudes should be extracted and correlated to the classification result from the standard test (mode shapes are not of interest in this phase). In the preliminary tests here performed, it has been shown that defected components will exhibit anomalous behaviour concerning resonance frequencies and amplitudes with respect to the non-defected ones. In particular, in the low frequency range mechanical defects of electronic components are typically related to problems or non-uniformity in the constraint, while in the high frequency range the effect of failures in the component structure can be usually observed.

Vibration measurements should be performed on line on the two parts of the power supply separated, before assembling, while they are put in vibration at least along two orthogonal axes (i.e. in a plane).

Once a significant data-base has been created, masks or neural networks based software can be used for classification of the results measured on the line. A similar approach was already successfully implemented by the author for on-line quality control of loudspeakers, as shown in [12]. In this way, destructive tests could be avoided and the control procedure could be automated and brought to a more objective and repeatable level for a high percentage of the production.

Finally, the time required for each test should be considered for the real industrial application. The measurement time is compatible with the production line, if one or few points are measured on each component. As an example, if 15 components of the power unit should be monitored in a frequency band up to 1 kHz with a frequency resolution of 5 Hz (200 spectral lines), a total measurement time of about 3 s is required. Considering that the scanning system takes about 0.1 s to move the laser spot from one measurement point to the consecutive one, the total testing time will be about 4.5 s. The measured signals can be thus post-processed to extract the information of interest.

The problem of quickly measuring the vibration on points sparsely defined in the space can be overcome only using a non-contact electro-optic technique coupled with an automatic scanning system, as the Scanning Laser Doppler Vibrometer here proposed.

In Figs 6 and 7 two examples of analyses performed with a reduced number of investigation points are reported. The image of the power supply from the vibrometer head camera (with the measurement points superimposed) is reported, together with the vibration spectra relative to the defected components. The detected mechanical failures have been found to be associated also to problems in the electrical functionality of the tested unit. In the first case (Fig. 6), 37 measurement points were utilised, with a total testing time of about 11.1 s, and an anomalous resonance of the main board was detected at 70 Hz. In the second case (Fig. 7), only 10 measurement points were employed (3 s of testing time) and a defect of a radiator was highlighted by the resonances at 130 Hz and 235 Hz with higher

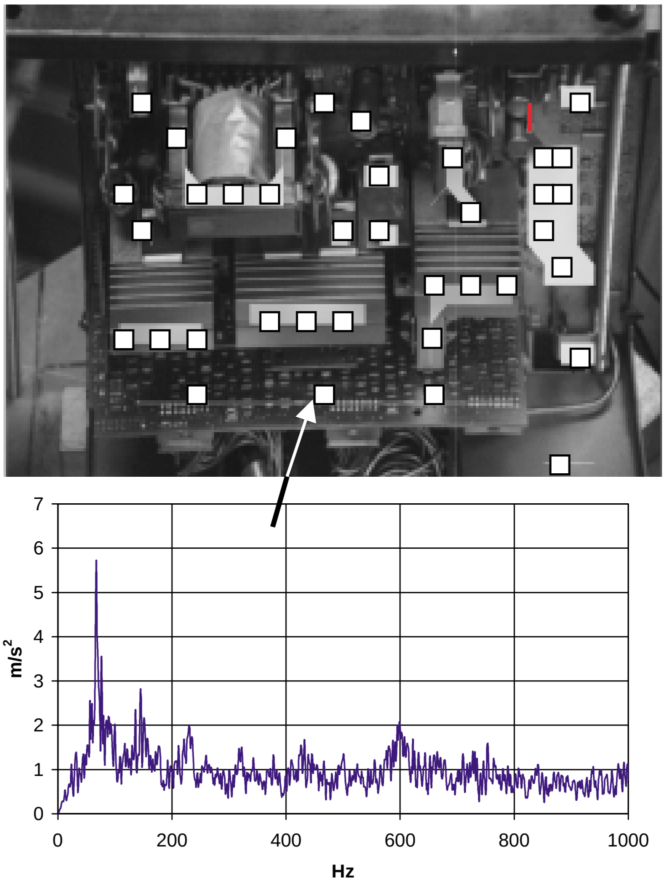

Fig. 6. Analysis with a reduced number of measurement points for on-line application: anomalous resonance of the main board detected at 70 Hz.

amplitudes with respect to the non-defected case. It is important to note that the observed differences are significantly larger than the repeatability of the results, which is in the order of 5–7%. This deviation takes into account both the repeatability of the measurement chain (below 1%) and the deviations in the natural vibration behaviour of the power supplies within the same classification sample ("good" or "defected"). In other words, the measured vibration amplitude at resonance for a component can not vary more than 5–7% in the same classification category, while this variation becomes significantly larger (30–40%) between "good" or "defected" components.

In these tests the power supply was excited by the shaker using a white noise driving signal.

5. Conclusions

In this work a novel idea for quality control of electronic devices by vibration testing is proposed and experimentally verified. The technique is based on the use of Scanning Laser Doppler Vibrometry (SLDV) to measure the vibration response of the different components under known dynamic excitation.

Tests are performed on a power supply, where several components are assembled together: boards, diodes, capacitors, dissipaters, transformers, etc. It is shown how it is possible to easily and rapidly detect the resonance of the different elements and to measure the vibration amplitude. The most critical components, from a mechanical point of view, can be identified and monitored.

Time duration of the tests is compatible with on-line requirements, if few measurement points are selected. To this aim, a valuable solution is to define a measurement grid for the SLDV with one point taken on each component. If more detailed information are required, e.g. for design purposes, a dense grid can be drawn, in order to carry out precise data on the dynamic behaviour of the object. This is useful to design the device in such a way as to minimise the mechanical stresses

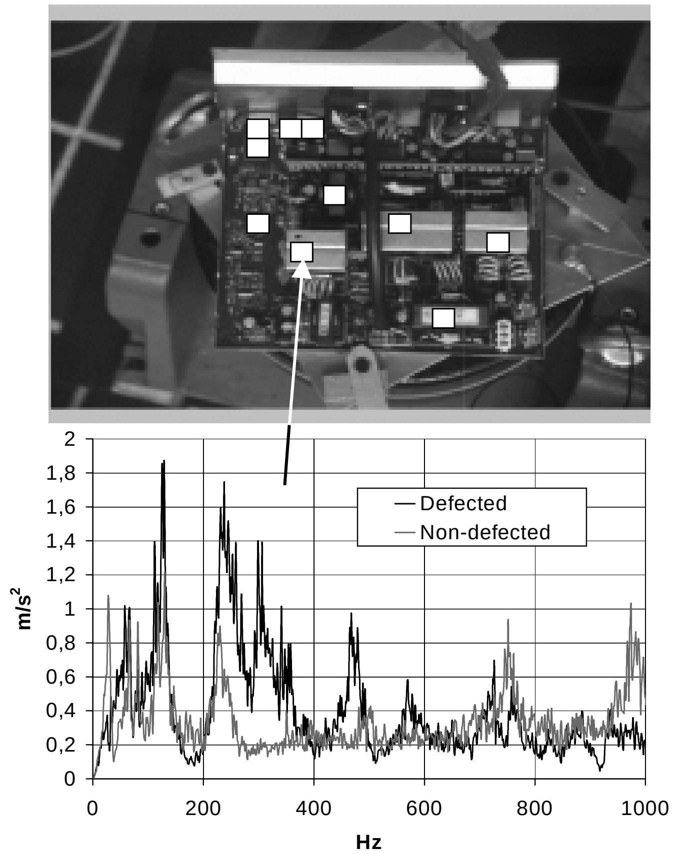

Fig. 7. Analysis with a reduced number of measurement points for on-line application: resonances at 130 Hz and 235 Hz of a defected radiator with higher amplitudes with respect to the non-defected case.

under transportation and operating conditions and thus to increase reliability.

Among the different electro-optical measurement techniques for vibration measurement, scanning vibrometry seems to be the only one with the metrological performances suitable for the present application. In fact, the full-field techniques (as holography or ESPI), which could be proposed for their capabilities of testing the whole object with one measure, has drawbacks related to the driving signal to be used for excitation, as they require a sinusoidal input. This is a problem mainly in terms of time, as one measure is required for each resonance frequency (about 20–30 in the performed tests). In addition, in this case the strong complexity of the 3D object shape poses severe limitations also to the accuracy of the achievable results.

On the contrary, laser vibrometry, measuring the signal directly in the time domain consecutively in different points, can be used with any kind of excitation signal (random, sweep, etc.). The tests can be thus designed according to the relevant International Standards and the measured data can be post-processed to extract the information of interest.

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