707. Non-destructive identification of vibrations of cardboard boxes

Artūras Dabkevičius[a], Nora Naginevičiūtė[b], Edmundas Kibirkštis[c]
Kaunas University of Technology, Department of Graphic Communication Engineering
Studentų 56-350, LT-51424 Kaunas, Lithuania
E-mail: [a]*arturas.dabkevicius@ktu.lt*, [b]*nora.nagineviciute@stud.ktu.lt*, [c]*edmundas.kibirkstis@ktu.lt*
Phone: +37037300236, **Fax:** +3703745168

(Received 03 October 2011; accepted 4 December 2011)

Abstract. The purpose of this paper is to analyze the influence of mechanical and physical defects in different cardboard boxes on vibrations by means of non-destructive diagnostics. This diagnostic method can be applied during manufacturing of boxes to identify damaged boxes and eliminate them. Boxes of different size and grammage were investigated before and after damaging them to determine the difference between their vibrations.

Keywords: cardboard, boxes, non-destructive, cardboard vibration, box with a cut, moistened box, crumbled box, cardboard boxes defects.

Introduction

One of the most popular materials for packaging is a cardboard [1]. This is because of its good chemical and physical properties. However, it is a very fragile material that can be damaged easily during transportation [2] or manufacturing process. Nevertheless this material is more popular compared to plastic or metal, because it is more ecological, easily recyclable and is fairly low cost.

As other research works show vibrations can be used to investigate various properties of different substances, including packaging materials [3]. The authors of this article in earlier studies performed investigations on vibrations of a multi-layered polymeric film [4] and vibrations of a sheet of paper in the printing machine [5]. Also a research on non-destructive diagnostics of uniformity of loading of the sheet of paper [6] was carried out; however it was concerned only with paper testing, while cardboard was not considered.

The process of fabrication of a cardboard box has a lot of steps, where it can be easily damaged. So application of vibrations can be helpful in detection of defects in the early stage of printing [3].

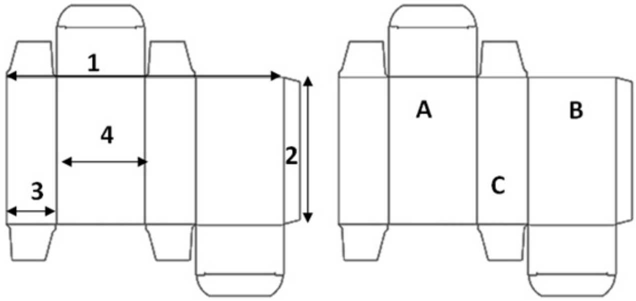
The purpose of this research is to establish a non-destructive methodology to identify the condition of a cardboard box. This diagnostic method can be applied during manufacturing of boxes or packing process to identify damaged boxes and eliminate them. Boxes of different size and grammage were measured before and after damaging them to determine the difference between their vibrations.

Methods and materials of experimental testing

The multilayer cardboard of two different grammage and made of recycled paper pulp and chalky on one side was used in the testing: Panka White - 310 g/m^2 (thickness - 0,39 mm); Multi Board - 350 g/m^2 (thickness - 0,45 mm). Such grammage of samples was selected because of its wide usage in the industry. The packages were cut by the die cutting machine YAWA MW 790A. The packages used in the test are free from printing, additional varnishing, other finishing or treatment.

The packages of two different sizes were tested. Each package was die-cut from cardboard of different grammage in the longitudinal (MD) or cross (CD) directions of paper molding.

Main measurements, grammage, measured sides and other parameters of the packages of different types are provided in Table 1 and marked by relevant numbers/letters in Fig. 1.



a) b)

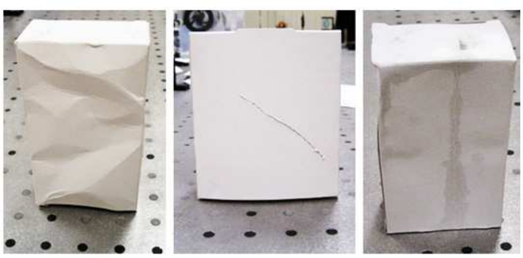
Fig. 1. Dimensions of the boxes (a)*, cardboard boxes walls measured in the experiment (b)**

Table 1. Technical characteristics of boxes used in the experiment

Type of the box	Grammage, g/m^2	Cardboard moduling	Cardboard boxes walls measured in the experiment**	1*, cm	2*, cm	3*, cm	4*, cm
I	310, 350	MD, CD	A, B, C	24	12,5	5	7,5
II				27	12	3,2	10,3

Influence of package vibration is assessed by this method depending on cardboard grammage, cardboard molding direction and defects. But the main aim of this noncontact test was to analyze the differences of vibration frequencies in the case of the packages free from defects and the damaged packages. Physical and mechanical defects of packages were as follows (Fig. 2): package moistened with water; crumpled; cut.

All experimental equipment was installed on the vibration-isolation table. General view of the testing setup is provided in Fig. 2. Vibrations of all package walls were scanned by the CCD laser displacement sensor KEYENCE LK-G82, and the distance between the sample and the head was adjusted by controller KEYENCE LK-GD5000.



a) b) c)

Fig. 2. View of the boxes with defects: a) crumpled box; b) box with a cut; c) moistened box

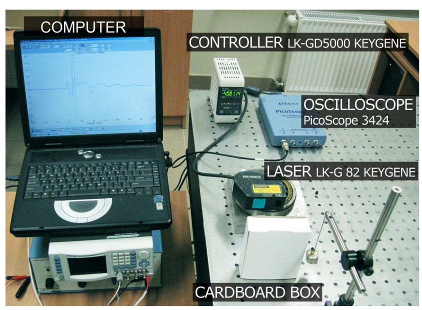


Fig. 3. General view of the test stand

An oscilloscope PicoScope 3424 recorded the vibrations generated by an impact. Information from the oscilloscope was transmitted directly to the computer where software PicoScope R5.21.2 was used for data processing and visualization. The computer monitor allowed observation of the decaying vibration curves of package walls and recording of the received values in the tables. Structural scheme of the experiment setup is provided in Fig. 4.

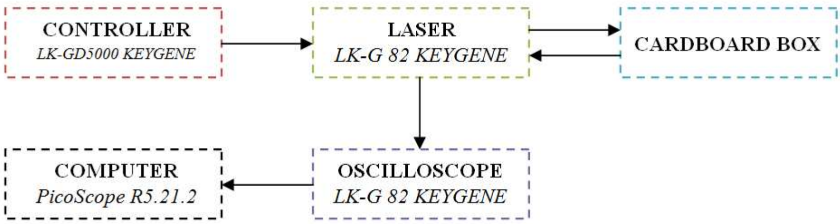


Fig. 4. Structural scheme of the experiment

The results obtained during the test have been expressed in vibration period (ms), and later vibration frequency was calculated.

Experimental results and their description

The results obtained during experimental testing are provided in Tables 2-4 and in Figs. 5-10. Experimental results demonstrate that vibration frequency of crumpled package decreases in comparison to the package which is free of defects. This indicates that the package under testing looses its rigidity. Therefore, when considerable surface defects are induced, the sample becomes less rigid. Difference of vibration periods can be clearly observed in the obtained diagrams.

It also should be noted that in the case of the intact package vibrations decay away within 180 ms after the impact, while vibrations of the crumpled package decays 350 ms after the impact.

Table 2. Results of the type I cardboard box

No.	Type of the box*	Cardboard molding	Side of the box (1 Fig.)	Grammage, g/m^2	Defects	Vibration period, ms	Vibration frequency, Hz
1	I	MD	A	350	Free	25,06	0,040
2			B			24,52	0,041
3			C			22,80	0,041
4			A		Crumpled	79,22	0,014
5			B			71,00	0,015
6			C			67,51	0,015

Table 3. Results of the type II cardboard box

No.	Type of the box*	Cardboard molding	Side of the box (1 Fig.)	Grammage, g/m^2	Defects	Vibration period, ms	Vibration frequency, Hz
1	II	MD	A	310	Free	8,91	0,113
2			B			11,62	0,087
3			C			10,77	0,093
4			A		Box with a cut	10,57	0,098
5			B			12,41	0,081
6			C			9,90	0,102

Table 4. Results of the type II cardboard box

No.	Type of the box*	Cardboard molding	Side of the box (1 Fig.)	Grammage, g/m^2	Defects	Vibration period, ms	Vibration frequency, Hz
1	II	CD	A	350	Free	3,29	0,309
2			B			2,56	0,345
3			C			4,19	0,239
4			A		Moistened	10,83	0,093
5			B			32,68	0,031
6			C			31,54	0,032

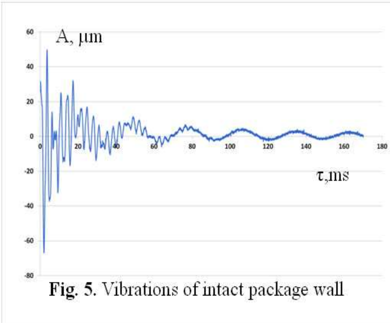


Fig. 5. Vibrations of intact package wall

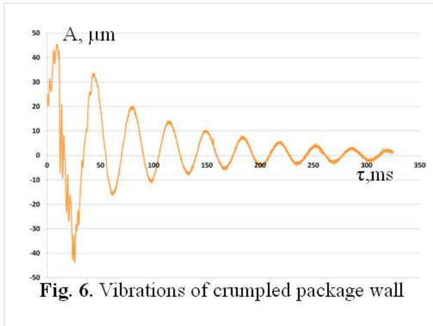


Fig. 6. Vibrations of crumpled package wall

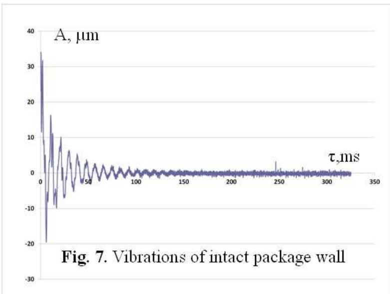


Fig. 7. Vibrations of intact package wall

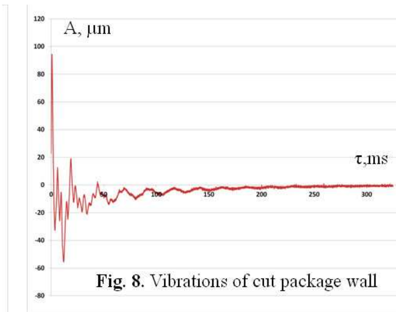


Fig. 8. Vibrations of cut package wall

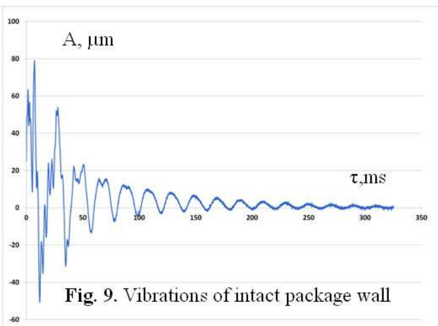


Fig. 9. Vibrations of intact package wall

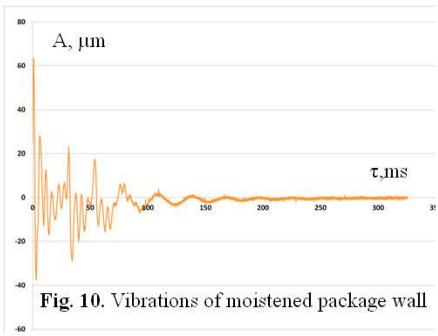


Fig. 10. Vibrations of moistened package wall

The results reveal that the cut has no considerable influence on the package vibration period and the obtained results are very similar. But differences can be noticed in the diagram. Amplitude of the cut package becomes negative.

Vibration period of the moistened package (comparing to intact package) increases considerably, while the frequency of the moistened package is reduced. The higher the frequency, the more rigid is the body. Therefore, the intact package is more rigid comparing to the moistened one. Diagrams of vibrations of the intact package and the moistened package are provided in Figs. 9-10.

It is also noticeable that the change of package cardboard molding direction also changes the vibration period and thereby the vibration frequency. In the case of longitudinal direction of paper molding the frequency is higher. Therefore packages with structure of such direction are considerably more rigid and durable.

Conclusions

The results of experimental test allow formulating the following conclusions.

Change of package cardboard molding direction also changes the vibration period and thereby the vibration frequency. In the case of longitudinal direction of paper molding the frequency is higher. Therefore the package with structure of such direction is considerably more rigid and durable.

Vibration frequency of crumpled (deformed) package decreases, and this means that the object looses its rigidity. Therefore, when considerable mechanical defects are incurred, the package becomes less rigid.

The cut has no considerable influence on the package vibration period and the obtained results are very similar to the package having no defects, but presence of package damage can be detected from the vibration amplitude.

Vibration period of the moistened package (comparing to intact package) increases considerably, while the frequency of the moistened package reduces.

Summary of the experimental results imply that the applied optical non-contact vibrometry method enables to estimate different physical and mechanical defects in the cardboard packages. This method of non-destructive diagnostics can be applied during manufacturing and usage of cardboard packages.

Acknowledgments

The authors would like to acknowledge the financial support by the Project of the European Union Structural Funds ”Postdoctoral Fellowship Implementation in Lithuania” within the framework of the Measure for Enhancing Mobility of Scholars and Other Researchers and the Promotion of Student Research (VP1-3.1-ŠMM-01) of the Program of Human Resources Development Action Plan.

References

[1] **Markstorm H.** Testing Methods and Instruments for Corrugated Board. Elanders Tofters, Sweden, 7-17 (2005).

[2] **Jarimopas B., Singh S. P., Saengnil W.** Measurement and Analysis of Truck Transport Vibrations Levels and Damaged to Packaged Tangerines during Transit. Packaging Technology and Science. 18: 173-188 (2005).

[3] **Kibirkštis E., Kabelkaitė A., Dabkevičius A., Ragulskis L.** Investigation of vibrations of packaging materials. Journal of Vibroengineering. 10(2): 225-235 (2008).

[4] **Ragulskis K., Dabkevičius A., Kibirkštis E., Bivainis V., Miliūnas V., Ragulskis L.** Investigation of vibrations of a multi – layered polymeric film. Mechanika. 80(6): 30-36 (2009).

[5] **Kibirkštis E., Kabelkaitė A., Dabkevičius A., Ragulskis L.** Investigation of vibrations of a sheet of paper in the printing machine. Journal of Vibroengineering. 9(2): 40-44 (2007).

[6] **Kibirkštis E., Kabelkaitė A., Dabkevičius A., Bivainis V., Ragulskis L.** Non-destructive diagnostics of uniformity of loading of the sheet of paper. Ultrasound. 64(3): 24-28 (2009).