TV packaging optimization of the frontal drop impact using equivalent static loads

Insik Han[1], Youngmyung Lee [2], and Gyung-Jin Park[3]

[1] LG Electronics, Pyeongtaek, Republic of Korea, insik.han@lge.com
[2] Hanyang University, Seoul, Republic of Korea, lymkd@hanyang.ac.kr
[3] Hanyang University, Ansan, Republic of Korea, gjpark@hanyang.ac.kr

1. Abstract
In electronic industries, packaging designs for protection are very important because electronic products are easily damaged in distribution. While distributing products, drop impacts are mainly issues. To protect electronic products, buffer materials like Expandable Poly-Styrene (EPS), and Expandable Poly-Propylene (EPP) are used in packaging. Therefore, packaging designers are effort to develop packaging design for improvement of product protection as well as reduction of the packaging size, and weight. These conditions should be considered as an objective functions or design constraints when optimizing a packaging design. However, it is difficult to apply gradient-based optimization methods to impact optimization problems because of the large nonlinearity of the problems which should be considered in the time domain. Although the capability of the computer has been developed and numerical algorithms have been advanced, drop impact optimization is still quite difficult owing to high non-linearity and numerical cost. The equivalent static loads method for non-linear static response structural optimization (ESLSO) has been developed for such nonlinear dynamic response structural optimization. equivalent static loads (ESLs) are linear static loads which generate the same displacement in the linear static analysis as those of the nonlinear dynamic analysis at a certain time step. Nonlinear analysis and linear static response optimization using ESLs are carried out sequentially until the convergence criteria are satisfied. A new ESLSO method is proposed for TV packaging shape optimization and is verified using a practical example. Design optimization of TV packaging is carried out to minimize weight packaging. The glass panel in TV is the most important part and design constraints are composed with it. The shape and size of EPS packaging are optimized. The weight is minimized and the size is optimized while the glass panel is protected in drop impact. The drop test of a TV packaging is analysed by LS-DYNA, and NASTRAN is used for optimization.

2. Keywords: Structural optimization, equivalent static loads (ESLs), Shape optimization

3. Introduction
Fragile electronic products, especially television have to be designed to operate reliably enough after shipping to consumer. Therefore, the research and evaluation is performed by the actual product to experiment in order to reduce the risk of product damage [1]. Also, researches considering the stress of the impact acceleration and the cushion of the product are performed using a high cost of computational simulation-based experimental design [2]. Recently, the development cycle of new products is becoming shorter. And prototype products design should be verified faster. However, making prototype products for performing experiments are very cost burden. Because this trends, computer simulations are used instead of direct experiment. Nevertheless, the simulation also requires both considerable time and effort to simulate the instability of the product. Therefore, it is necessary to shorten the overall time required for development by shortening the time required for the simulation. The products are packed in packaging material to prevent damage like deformation and crack during transporting to consumer. The shape and form of the packing material varies widely depending on the type of product. Most of TV packaging design is a typical area for performing design engineers rely on the know-how and intuition. To verify the TV packaging design, it should be performed the standard tests. The drop test is a typical standard test. TV drop simulation is performed based on the nonlinear dynamic response analysis. And time required for a nonlinear dynamic response analysis is very long. Design of Experiments also commonly used when performing an optimal design through a non-linear dynamic response analysis. For optimal design problem of a large number of design variables using a Design of Experiments is a necessary nonlinear dynamic response analysis and increases the number of very large and inefficient. Therefore, the development of new techniques is required in order to reduce optimal packaging design time. In this research, optimization of TV-packing is performed using ESLSO. The finite element model of an actual TV-set from LG Electronics Inc. is utilized as a reference. Nonlinear dynamic analysis is carried out using LS-DYNA 971 [3], linear static response structural optimization is conducted by using NASTRAN [4]. The final design is compared with the reference model and verified by testing prototype.

4. TV packaging and drop test
4.1. TV packaging

The TV package is consist of cushion and paper box to protect the product. The cushion is usually made with EPS or EPP that materials are good in the efficiency for the compression. However, it is hard to simulate accurately because there is a severe non-linearity by its density and compression strain rate of the material. So, accurate physical properties should be obtained through experiments. In this research, the stress strain curves of the EPS material are obtained by material experiment for accurate computer simulation.
The Universal Transverse Machine (UTM) in Figure 1 a) is difficult to test in fast compression strain. So, dynamic drop tester in Figure 1 b) is performed to obtain stress-strain curve in high strain rate.

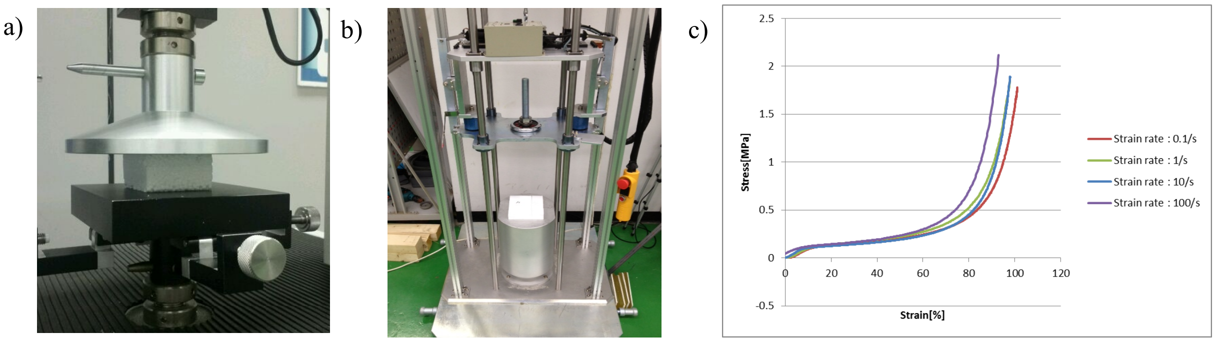

Figure 1: Material experiments: a) static UTM, b) dynamic drop tester, c) strain-stress curve for EPS

4.2. Drop test
There are various standard tests for verifying the distribution of TV products. Serious damage to the product in the distribution is derived mainly from the impact on the front of the product. Front drop test is performed to verify

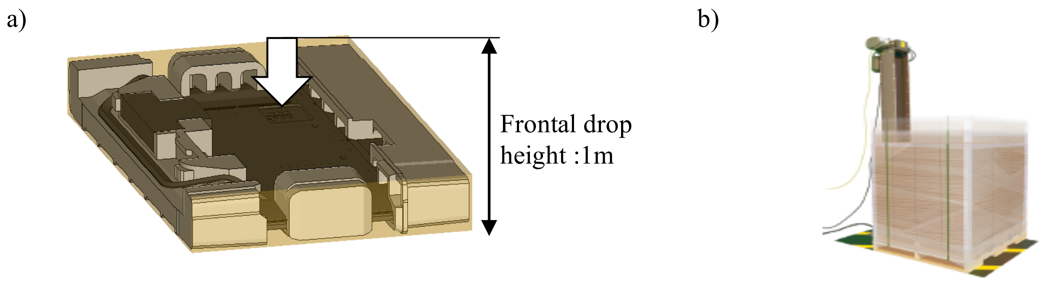

Figure 2: Frontal drop test: a) drop height, b) drop test machine

the design of packaging and to determine proper operation. The height of the drop varies by weight of the product. In this research, the front drop height of TV is 1 meter.

5. Equivalent static loads method for nonlinear dynamic response structural optimization
The process of calculating ESLs is described in detail. Eq.(1) is the governing equation of nonlinear dynamic response analysis.

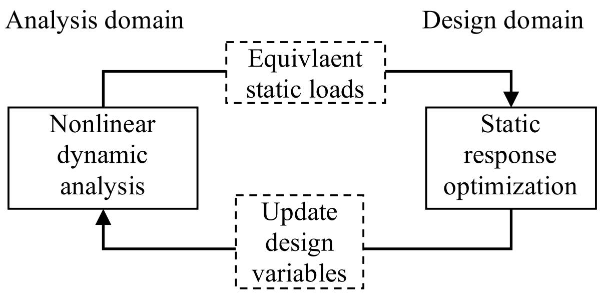

Figure. 3 Schematic flow of equivalent static loads method

$$\mathbf{M}(\mathbf{b},\mathbf{z}(t))\mathbf{z}_{\mathrm{N}}(t)+\mathbf{K}_{\mathrm{N}}(\mathbf{b},\mathbf{z}(t))\mathbf{z}_{\mathrm{N}}(t)=\mathbf{f}(t)\ (t=0,\quad ,l) \qquad (1)$$

where $\mathbf{b}\in R^n$ is the design variable vector, n is the number of design variables, $\mathbf{M}$ is the mass matrix, $\mathbf{z}_{\mathrm{N}}(t)$ is

the acceleration vector, $\mathbf{K}$ is the stiffness matrix, $\mathbf{z}_N(t)$ is the displacement vector, and $\mathbf{f}(t)$ the is dynamic load vector, subscript N means that it is from nonlinear analysis, t is time and l is the number of time steps.
The ESLs vector $\mathbf{f}_{eq}(s)$ is calculated as the product of linear stiffness matrix $\mathbf{K}_L(\mathbf{b})$ and the displacement vector $\mathbf{z}_N(t)$.

$$\mathbf{f}_{eq}(s) = \mathbf{K}_L(\mathbf{b})\mathbf{z}_N(t); \quad s = 1,\ldots,l \tag{2}$$

The overall process is as follows:

Step 1. Set the initial design variables (cycle number: $k = 0$, design variables: $\mathbf{b}^{(k)} = \mathbf{b}^{(0)}$).
Step 2. Perform nonlinear dynamic response analysis with $\mathbf{b}^{(k)}$.
Step 3. Calculate the ESLs using Eq.(2).
Step 4. Solve the linear static response structural optimization problem with ESLs.
Step 5. When $k = 0$, go to Step 6. When $k > 0$, if the convergence criterion is satisfied then terminate the process. Otherwise, go to Step 6.
Step 6. Update the design variables, set $k = k + 1$ and go to Step 2.

6. TV Packaging optimization using equivalent static loads

6.1. The finite element model of TV

In this research, we use commercially available finite element model of the television from LG and perform the optimal design. For optimal efficiency of the design, we modify the front packing in the form of a rectangular shape. From now on, we call the modified model to the 'reference model'. This reference model Figure. 3 is composed of 504,438 elements and 471,079 nodes. The four types of packaging materials protect the TV, and the outside is packaged in a box. Non-linear dynamic response analysis using the LS-DYNA performed the front drop simulation. NASTRAN was used as the structural optimization solver. The algorithm used in structural optimization is a method of feasible directions (MFD).

6.2. Shape optimization of TV packaging

Figure 34 shows the 6 design variables and displacement constraints. The objective function is the mass of the packing, and shape optimization is carried out. The displacement constraints are defined using the distance from the fixer A to the fixer B. The fixer A and B are structures for holding TV panel from set. The detachment of the panel is defined as the relative distance between the two structures. Using the displacement constraints, the detachment of the panel is constrained. The lower bound for the constraint is 0 mm.

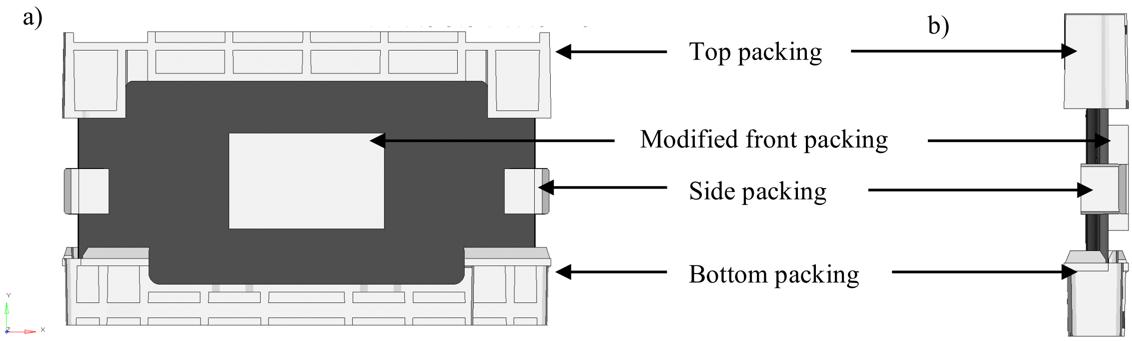

Figure 2: The finite element model of TV : a) Front view, b) Side view

Design formulation is as follows:

Find	$b_i \ (i = 1,2,\ldots,6)$	(2)
to minimize	$mass\ of\ the\ packing$	(3)
subject to	$\delta_k > 0mm \ (k = 1,2,\ldots,28)$	(4)

where b_i is the i th design variable that is perturbation vector of the packing shape, and δ_k are the relative displacements of the fixer A and B. On the upper panel, there are 12 attached points between the panel and the set. And on the side panel there are 16 attached points. Total attached points are 28.

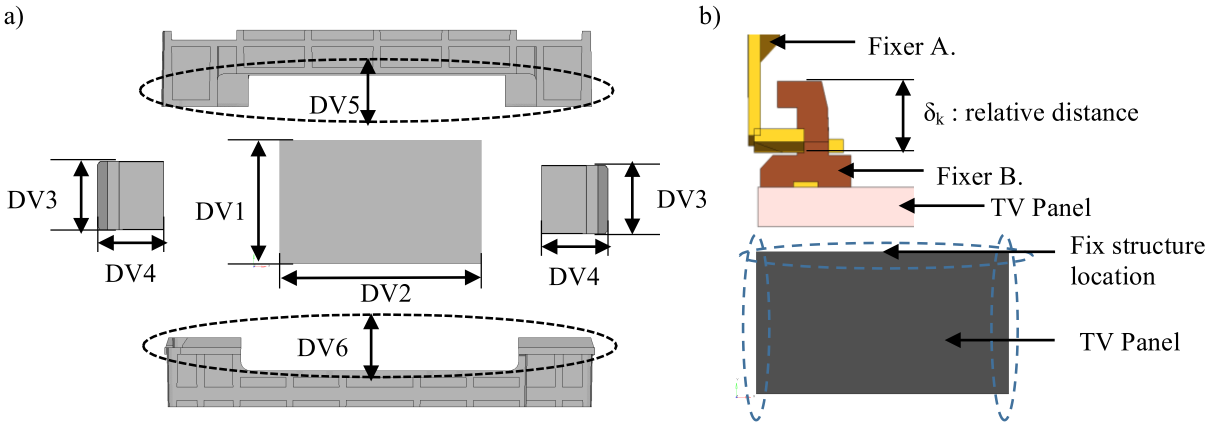

Figure 4: Design variables and constraints :
a) Perturbation vectors of shape optimization. b) Displacement constraints

Figure shows the history of optimization. The process converges to the optimum solution in the 6st cycle. The mass is reduced by 11% from 617g to 553g while the displacement constraints are satisfied.

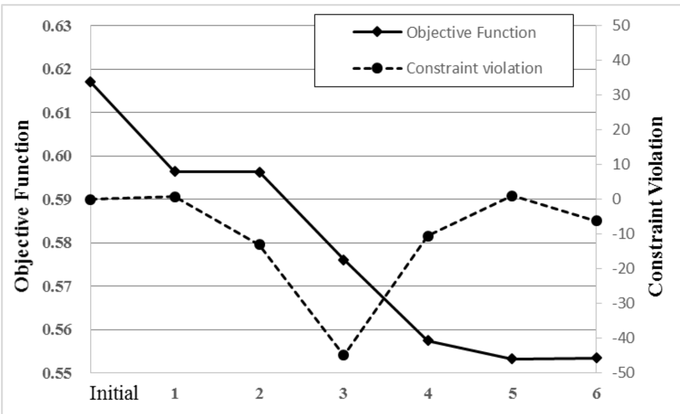

Figure 5: History of objective function and constraint violation of drop test

6.3. Verification test of the results

In order to verify the optimum design results, drop test was performed by pilot sample. As a result of the test, the pilot sample was working properly without damage.

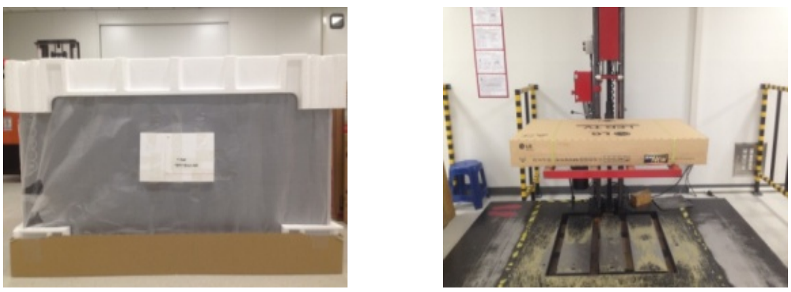

Figure 6: Verification test of the results : a) Pilot package, b) Drop test

7. Conclusions

Nonlinear dynamic response structural optimization of high-fidelity finite element model seems to be almost impossible in conventional gradient based optimization due to high nonlinearity and time-dependent behavior. In this research, TV package optimization with the frontal drop test is carried out using ESLM. Practical examples are solved by the proposed method.

TV package optimization is carried out to determine 6 design variables. The optimum shape is derived by performing 6 nonlinear dynamic analyses. The displacement constraint is satisfied and the mass is reduced by 11%. Verification test by pilot samples is performed and the pilot sample is working properly. As a result of verification test, using ESLM for optimizing design of TV package is efficient.

Table 1: Comparison of packing shape of the initial and the optimum

Cycle No.	DV1	DV2	DV3	DV4	DV5	DV6
Initial	257.5	418.0	122.2	120.0	233.0	210.0
Optimum	220.55	370.3	99.11	108.5	220.4	191.1

8. References

[1] Kim, C. S., Bae, B. K., and Sung, Do. Y., 2010, "Drop Analysis of a Package and Cushion Performance of Drum Washing Machine," Trans. Korean Soc. Mech. Eng. A, Vol. 34, No. 11, pp. 1733~1740.X. Liao, Q. Li, X. Yang, W. Zhang and W. Li, Multiobjective optimization for crash safety design of automobiles using stepwise regression model, *Structural and Multidisciplinary Optimization*, 35 (6), 561-569, 2008.

[2] Kum, D. H., Kim, Won. Jin., Kim, S. D., and Park, S. H, 2004, "Optimal Design for Cushioning Package of a Heavy Electronic Product Using Mechanical Drop Analysis," Korean Soc. for Noise and Vibration Eng., Vol. 14, No. 2, pp.128~135.

[3] LS-DYNA 971 version user's manual, *Livermore Software Technology Co.*, CA, 2007.

[4] NASTRAN user's guide, *MSC Software Co.*, Santa Ana, CA, 2013.