Thermal Analysis and Experimental Validation on TFT-LCD Panels for Image Quality Concerns

Chung-Yi Chu, Min-Chun Pan and Johnson Ho*
Department of Mechanical Engineering, National Central University, Taiwan, ROC
* Spectrum Research and Testing Laboratory (johnson@srtlab.com)
Email: 92343016@cc.ncu.edu.tw, Tel: (886)3-4267390

Abstract

The heat source from cold cathode fluorescent lamps (CCFLs) in the backlight module of a TFT-LCD TV causes the cell assembly to warpage. The extruding phenomenon, appearing between the cell and its bezel, leads to defects in display of the TFT-LCD TV. The study successfully simulates and predicts the process by finite element analysis (FEA), computational fluid dynamics (CFD), and structure-heat transfer. The paper also shows the efficient experimental verification which uses kinds of physical sensors to measure the temperature variation and thermal stresses on the surface of LCD-TV cell. The achievements and techniques can be employed to analyze and design the geometric parameters of different components in LCD-TV modules for product optimization.

Keywords : FEM, CFD, TFT-LCD TV, Backlight module, Warpage

1. Introduction

The direct type of backlight module substitutes for the side-edge type for the demand of high radiance and high vision angle in LCD-TV market. The direct type module utilizes many CCFLs directly under the screen while the side-leading type module only sets CCFLs at each side of the screen. However, it comes after that the high heat energy originated from the CCFLs in the direct type module caused thermal problem, emitted heat results in a high thermal strain on compound structures.

The study is using a 23” commercial TFT-LCD (as shown in Fig.1) to investigate the thermal deformation of compound structures that arises from the heat source of CCFLs by conducting a verification process with both experimentation and FEA.

Kim et al.\(^1\) applied the FEM heat transfer method to analyze the influence of thermal deformation of a shadow mask in a cathode ray tube (CRT), which causes abnormal display. Kim et al.\(^2\) also studied the influence of thermal deformation of a special shadow mask in a color CRT by using the FEM heat transfer method and including the consideration of heat radiation as well. Besides Kim et al.\(^3\) investigated further about the flat CRT and successfully enhanced the endurance of the front bezel and side-fixing structures against thermal stress as well as reduced their weight. Park et al.\(^4\) analyzed the thermal deformation of the perforated sheet inside the shadow mask by FEM. The results of temperature distribution shown in the finite element analysis and experimentation are satisfied. Cheong et al.\(^5\) analyzed the temperature distribution of every LCos component and demonstrated that using FEM can reduce the lead time for developing product.

Two major parts of this paper are FEA and experimentation. The commercial package, ANSYS, is used for finite element simulation. A data acquisition system accompanied with thermocouples, strain gauges and a position detection sensor is established to measure the physical changes on the LCD surface. The diffuser plate within the backlight module of the TFT-LCD deforms caused by the heat of CCFLs and then pushes the liquid crystal panel. Additionally, the liquid crystal panel also deforms locally by heat, which is called warpage or cell bending. When the warpage happens, the panel is squeezed between the front bezel and the fixing frame. This unwanted effect results in stress concentration and an abnormal distribution of liquid crystal in the panel. Light radiating from the CCFLs and passing through the abnormal panel will display a distorted image.

Fig. 1: Front and side view of 23" TFT-LCD TV to be studied.

2. Number analysis

The fluid-structure coupled analysis includes CFD and structural heat transfer\(^6\)-\(^14\).

2.1 CFD process

The analysis starts first at the backlight module component of TFT-LCD as shown in Fig.2. Figure 2(a) and (b) shows the right view of the TFT-LCD the CCFLs with air layer, respectively. Backlight module is not a vacuum actually. Therefore, this simulation will focus on the heat distribution of the air layer, whose heat is given by 12 CCFLs. The analysis is using the ANSYS-Flotran to compute the heat radiation from CCFLs with air layer, respectively. Backlight module is not a vacuum actually. Therefore, this simulation will focus on the heat distribution of the air layer, whose heat is given by 12 CCFLs. The analysis is using the ANSYS-Flotran to compute the heat radiation from CCFLs and the heat convection of the air layer. The only way to cool down in current design is transfer the heat outside via structures for no heat sink and forced convection devices embedded.

Figure 3 illustrates the flowchart of the CFD computation procedure with six steps. The process is finished while the result is reasonable. Otherwise, steps 1 to 6 will be repeated again.
Fig. 2: (a) Side view of the TFT-LCD TV for the CFD computation. (b) The CCFLs and the air layer.

Fig. 3: Flowchart of CFD computation.

Fig. 4: Temperature distribution by CFD analysis.

Fig. 5: Vector expression of the air flow velocity by CFD analysis.

Fig. 6: Pressure distribution of the air chamber by CFD analysis.

The parameters of air temperature, air flow-rate, air pressure and heat flux of CCFLs need to be prepared before the CFD modeling. As the CCFLs are supplied with a 5.4-W power source (900V, 6mA) each, thus the heat flux can be computed by Eq. (1).

\[
\text{Lamp output power} = \frac{5.4}{\text{Surface area of lamp} \times \text{Lamp length}} = \frac{5.4}{2 \times 0.0015 \times 0.5085} = 1127 \text{ W/m}^2
\]  

(1)

2.2 Discussion of CFD results

When lighting up these 12 CCFLs, air close to the CCFL will be heated up and will rise for its low density against the other high density air. Because of buoyancy, the air starts to natural convection.

The CFD computed result is that the temperature of the upper air is higher than that of lower air\(^5\). CFD temperature in the upper air layer of TFT-LCD TV Backlight module is higher than in the down layer as shown in Fig. 4. The max temperature is 54°C and the min temperature is 25.102°C, and the max velocity of air flow shown in the Fig. 5 is \(0.095054 \text{ m/s}\) in the expression of vector. Pressure in the upper side is higher than that in the down side as the Fig. 6 shows, the max pressure is \(0.098846 \text{ N/m}^2\) and the min pressure is \(-0.06689 \text{ N/m}^2\). Data comparison of Simulation and measurement on CCFLs is shown as the Fig. 7.
2.3 FEA of structure heat-transfer

Figure 2 shows the CCFLs and air layer. When finishing the CFD computation, the boundary temperature of the enclosed air can be obtained. The next step is to input these boundary temperature data to FEA to compute the influence of the heat transfer from backlight module to structures.

Figure 8 shows the procedure of FEM heat transfer analysis. There are ten steps about the FEM computation. Step 1 is to determine the target model and parameters. Step 2 is to build up the model and mesh into pieces. Step 3 is to input the CFD results. Step 4 is to set up the parameters of the heat transfer calculation. Step 5 is to compute the heat transfer of structures. Step 6 is to call out the temperature data of structure as input. Step 7 is to set up the parameter of heat deformation calculation. Step 8 is to compute the thermal deformation of structures. Step 9 is to call out the thermal deformation of structures. Step 10 is to judge the result. The process will finish if the result is reasonable. Otherwise, step 1 to step 10 will be running repeatedly. The models in the structure analysis must be the same with that in CFD analysis exactly.

Figure 9 shows the temperature distribution by structural heat-transfer analysis, the FEA of structural heat-transfer requires the temperature data of the whole TFT-LCD TV. As a consequence, the temperature of the LCD panel should be measured for thermal stress analysis and thermal strain analysis.

3. Distorted display on the TFT-LCD TV

When a LCD-TV set works, CCFLs radiate light-source with high intensity into backlight module, including diffuser plate, diffuser sheet, and brightness enhancement film etc. Regularly, the light traveling toward the cell must be polarized and further produce RGB colors to compose patterns, illustrated as Fig.10. However, the cell affected by the thermal stresses due to the temperature on the CCFLs will touch its bezel as shown in Fig.11(b), while there is nothing happened under the rest of the TV as shown in Fig.11(a). Furthermore, Fig.12 shows the diffuser sheets deformed due to the thermal expansion also extrude the liquid-crystal cell. The thermal stresses around the contact region between the cell and the bezel must seriously affect the distribution of liquid crystal and lead to defects in the performance of TV-display. Figure 13 shows the whitening defects at the indicated corners while the normal screen is blue.
4. Experimentation

The study has set up a measurement system for observing the process of thermal variation and deformation on the cell, illustrated as Fig.14. Figure 15 illustrates the measurement sensors and apparatus from NI (National Instrument) Co., and the integrated interface and driving program are accomplished by the Labview software. Figure 16 shows the arrangement of measurement sensors on the TV cell in the experiment. The verification is designed to investigate the TV panel assembled with and without the frame.

1. The experiment designs to measure the surface temperature at three places on the cell, i.e. locations T1, T2, and T3 (shown as in Fig.16). Figure 17 shows the results that T1 is 40°C, T1 is 38°C, and T3 is 35°C. Therefore, the temperature at the higher place of the cell surface is larger than that at the lower location. When the TV set works, CCFLs in the backlight module heat the air and cause it to produce the phenomenon of natural convection. Eventually, the temperature variation can lead the top portion of the cell to warpage, while the temperature change on the cell reaches stable after lighting the CCFLs for 1 hr.

2. NCDS (Non-Contact Displacement Sensor) can measure the deformation and displacement in the Z direction on the cell surface. Figure 16 indicates the locations of NCDS in the experiment. The result of the panel with a frame shows in the Fig.18(a) and the deformation is 0.4 mm. Fig.19(a) reveals the records of the panel unframed and the deformation is 2.9 mm.

3. The study uses strain gages to measure the strain in the Y direction on the cell surface. The results of the panel equipped a frame at location S2 (Fig.16) show in the Fig.18(b), and Fig.19(b) presents the variation for the panel unframed. Apparently, the strain on the cell of the panel unframed is 4-times larger than that of the panel with a frame.
Fig. 15: System flow of experimentation with NI DAQ system.

Fig. 16: Illustration of sensors mounted on the surface of cell assembly.

Fig. 17: Temperature rising vs. time on the TV cell after lighting.

Fig. 18: Strain and displacement variation with bezel after lighting.

Fig. 19: Strain and displacement variation without bezel after lighting.

5. Conclusions

The study addresses the effective computational simulation of TFT-LCD TVs by FEM, which uses the natural convection effect and structure-heat transfer analysis. The experimental technique, measuring temperature and stress variation through kinds of physical sensors, is also presented for verification. The results show good compatibility to demonstrate that the simulation process successfully predicts the warpage phenomenon and defects of display in the cell module of TFT-LCD TVs. The study has set up a systematic analysis and experimental measurement. The achievements can assist engineers in designing, analyzing, and testing the LCD-TVs. The technology will promote the ability, furthermore, about the research and development of FPD (Flat Panel Display) industry.

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References

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