General paper

Glass Tube Design for CRT (Cathode Ray Tube)

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Abstract: Stress and deformation of cathode ray tubes (CRTs) under atmospheric pressure and implosion protection band tightening were analyzed using a finite element method (FEM). The stress and deformation of the tubes were measured experimentally by using strain gages and three-dimensional position measuring techniques. The experimental results showed close agreements with those of the simulation. The location of the highest tensile stress and the effects of tightening of the implosion protection bands on the stress and deformation of the tube were clarified. Long-term reliability of the tubes were also studied by using these simulation techniques and the strength characteristics of the CRT glass taking account of surface roughness and delayed fracture.

Key Words: Cathode ray tube, Glass tube, Finite element method, Glass, Strength, Long-term reliability

1. INTRODUCTION

Cathode ray tubes (CRTs) have long been the dominant display device for computer terminals and television sets. Recently, larger, flatter and lighter tubes have been demanded. Therefore, simulation techniques for optimizing the structural design and highly accurate procedures for evaluating the mechanical reliability have become important. The main mechanical loads of tubes are atmospheric pressure, the tensile force due to the implosion protection structure, and impact loads. The authors have been studying the strength of the tube for some years now [1-4]. Although various simulation techniques have been applied to the structural design of CRTs, few take proper account of ways to evaluate mechanical reliability [5-8].

This paper describes the experiments and analyses on the effect of atmospheric pressure and implosion protection structure on the stress and deformation of the tubes, and the strength of CRT glass. The study was also carried out on the long-term reliability of glass tube designs under atmospheric pressure.

Fig. 1. Configuration of CRT.

2. EXPERIMENTAL AND ANALYTICAL METHODS

Figure 1 shows the configuration of a CRT. The tube is composed of a panel, a funnel and a neck. Air is pumped out from the inside of the tube to make a vacuum before it is subjected to implosion treatment using shrinkage-fitting or tension band tightening. The authors evaluate the deformation and stress generated in the tube of a tension band type CRT through experiments and analyses using a finite element method (FEM).

2.1. Experimental Method

The panel face deformations in the z direction, before and after air injection and cutting the tension band, were measured with a three-dimensional position measuring instrument. The strains before and after the evacuation were measured by attaching a two-axis strain gauge (radial in the v direction and in the h direction vertical to v, see Fig. 1) at points on the panel's outer surface. In the above experiments 14-inch tubes were used. Further, the strains before and after cutting the tension band were measured using 14-inch tubes (single-row/single-layer band) and 37-inch tubes (multi-row/multilayer bands). In this experiment, the effects of the presence and absence of the rim band and the winding style of the tension band on the stress and deformation of the tubes were also investigated.

2.2. Analytical Method

The 1/4 structure shown in Fig. 1 was modeled considering the symmetry of the CRT structure and the load about the x and y axes. In order to find the effect of the difference between element types, the 14-inch tubes were modeled using two elements of shell and solid types. Figure 2 shows the FEM models for the atmospheric pressure analysis. Further, in order to find the effect of the tension band, the shell models were prepared for 14-inch tubes without the rim band and 37-inch tubes with the rim band. Figure 3 shows the FEM models for the tension band

analysis. For the boundary conditions, the z direction of the neck bottom was constrained. For the load conditions, pressure of 0.1MPa was applied to the whole of the tube surface for the atmospheric pressure analysis. However, for the tension band analysis, the pressure from the tightening force of the tension band was applied to the tension band element. The mechanical properties of materials for this simulation are shown in Table 1. The commercial FEM code MSC/NASTRAN was used.

3. ATMOSPHERIC PRESSURE AND TENSION BAND TIGHTENING ANALYSES FOR SMALL CRT TUBES

In this chapter the values obtained through experiments and analyses are compared in order to verify the validity of the present modeling using the 14-inch CRT.

3.1. Experimental and Analytical Results for Tubes under Atmospheric Pressure

The experimental and analytical results (shell and solid models) are given below. Figure 4 shows the panel face

(a) Shell model (b) Solid model
Fig. 2. Finite element models (atmospheric pressure).

(a) 14-inch tube (b) 37-inch tube
Fig. 3. Finite element models (tightening force).

Table 1. Mechanical properties of materials

	Panel	Funnel	Neck	Tension band Rim band
Tensile modulus E (GPa)	68.6	68.6	61.8	206
Poisson's ratio ν	0.23	0.24	0.24	0.30

deformation after the evacuation in the z direction on the diagonal axis of the 14-inch CRT. Figure 5 shows the stress σ_v on the minor axis of the tube. The vertical axis in Fig. 4 is normalized by the maximum deformation $\delta_{z \max}$ of the shell model after subtracting the deformation at the base point G from the deformation at each point. The vertical axis in Fig. 5 is normalized by the maximum tensile stress $\sigma_{\max}$ of the shell model. The horizontal axes D in both figures indicate the distance along the tube surface from the face center. The experimental results correspond well to the simulation. The absolute analytical values tend to be higher in the shell model and lower in the solid model than the experimental values. This is probably attributed to the bending mode, which can be easily simulated by the shell model, and the rigid behavior of the solid model due to the one layer partition in the thickness direction. It can, therefore, be deduced that the shell model is appropriate to conduct the sufficient structural evaluation.

3.2. Experimental and Analytical Results for Tubes Tightened with Tension Bands

Figure 6 shows the σ_v on the minor axes of a 14-inch CRT (single-row/single-layer tension band without a rim band) and a 37-inch CRT (multi-row/multilayer tension

Fig. 4. Comparison of FEM results with experiments on panel surface deformation (atmospheric pressure).

Fig. 5. Comparison of FEM results with experiments on CRT surface stress (atmospheric pressure).

bands with a rim band), with the values obtained from both experiments and the shell model analysis. The stress is normalized by the band tensile stress σ_T (tension band tensile force divided by sectional area). The experimental results correspond well with the analytical results, as in the case of the atmospheric pressure analysis of the shell model. This suggests the validity of the shell model on the tension band tightening style (single-row/multi-row, single-layer/multilayer), the surface pressure application, and the rim band rigidity.

Fig. 6. Comparison of FEM results with experiments on CRT surface stress (14-, and 37-inch tubes, tightening force).

4. ATMOSPHERIC PRESSURE AND TENSION BAND TIGHTENING ANALYSES FOR LARGE CRT TUBES

4.1. Atmospheric Pressure Analysis

The atmospheric pressure analysis of a 37-inch tube was conducted using the method given in Section 2.2. Figure 7 shows the tube deformation and the contour of the maximum principal stress σ_1 of the outer surface. The tube has a large inward deformation on the panel face due to atmospheric pressure. It also has an outward deformation on the panel

(a) Deformation. (b) Maximum principal stress contour of CRT surface.
Fig. 7. FEM results (37-inch tube, atmospheric pressure).

skirt. In Fig. 8, the distribution of the maximum principal stress σ_1 on each axis of the tube's outer surface is normalized by the maximum tensile stress of $\sigma_{1 \max}^*$ (corresponding to the $\sigma_{1 \max}$ on the minor axis of the tube's outer surface). Compressive stress is generated in the panel face center on the tube's outer surface. This compressive stress changes into tensile stress on approaching the edge and produces high tensile stress from the edge of the major-minor axes to the frit seal. In contrast, the minimum principal stress (not presented here) around the edge of the major-minor axes of the tube's inner surface is compressive, and the maximum/minimum principal stresses are both in the v direction. Thus, the large bending stresses are found to act in the v direction around the edge of the major and minor axes of the tube.

4.2. Tension Band Tightening Analysis

The effect of tension band tightening on the tube was investigated using the 37-inch tube with rim band shown in Fig. 3. Figure 9 shows the deformation of the tube and the contour distribution of the minimum principal stress σ_2 of the tube's outer surface. Figure 10 shows the minimum principal stress σ_2 for each axis of the tube's outer surface normalized by the band tensile stress. The tube is deformed inwards at the panel skirt because of the surface pressure

Fig. 8. Maximum principal stress distribution along each axis of CRT surface (37-inch tube, atmospheric pressure).

(a) Deformation (b) Minimum principal stress contour of CRT surface
Fig. 9. FEM results (37-inch tube, tightening force).

received from the tension band that caused compressive stress on the outer panel skirt. Conversely at the panel face, the tube is deformed outwards, which produces tensile stress on the outer surface. These deformation and stress modes work to reduce the aforesaid deformation and stress caused under atmospheric pressure. The tension band generates the highest compressive stress on the panel face diagonally due to the shape of the periphery of the panel skirt, on which the band was tightened.

5. DESIGN OF GLASS TUBE

5.1. Reduction of Atmospheric Pressure Deformation and Stress Due to Implosion Protection Structure

The face center deformation $\delta_{z(A.P)}$ due to atmospheric pressure is reduced by the deformation $\delta_{z(T.B)}$ due to the tension band tightening. The reduction rate $\delta_{z(T.B)} / \delta_{z(A.P)} \times 100$ (%) is defined as the sagging rate S , which is used as a design index to evaluate the implosion protection capability. Figure 11 shows the relation between the sagging rate and

Fig. 10. Minimum principal stress distributions along each axis of CRT surface (37-inch tube, tightening force).

Fig. 11. Effect of tension band on sagging (37-inch tube).

the distribution of tensile force on the panel side and funnel side. In Fig. 11, the vertical axis is normalized by the sagging rate when the ratio of the panel side/funnel side is 50%/50%. Figure 12 shows the relation between the sagging rate and the stress. This is obtained through normalizing the maximum principal stress under atmospheric pressure for each axis of the tube's outer surface by the maximum tensile stress of $\sigma_{1 \max}^*$ from Fig. 8. From Fig. 11, with the total tensile force fixed, it can be understood that the sagging rate is maximized by tightening the band on the funnel side. In contrast, from Fig. 12, it can be understood that the tensile stress is minimized by tightening the band on the panel side. Further, the stress reducing effect of the tension band is not uniform throughout the tube. Thus, it is necessary to decide the tensile force and the band position properly by the simulation.

Fig. 12. Relation between sagging rate and maximum tensile stress $\sigma_{1 \max}$ along each axis (37-inch tube).

5.2. Strength Characteristics of Tube Glass

Figure 13 shows the maximum tensile stress on each glass component of the tube under atmospheric pressure normalized by the maximum tensile stress of the panel. It also shows the strength ratio obtained through normalizing the static bending strength of each glass component by the strength of the panel glass. These strengths were obtained by the separate work [9]. The comparison shows that the stress ratio is high at the panel compared to the stress ratio for other glass components. This proves that it is worth paying attention to the panel glass strength.

5.2.1. Static strength characteristics

In the static strength tests (4-point bending) of tube glass, the stress loading speed was set to approximately 10 MPa/min. Figure 14 shows the Weibull distribution of the static strength for polished specimens (surface roughness: 0.04 μm or less) and specimens abraded with #150 emery (surface

Fig. 13. Comparison of maximum tensile stress and static bending strength for each glass component.

roughness: 0.03 to 0.075 mm) in air, for panel glass 5- and 10-mm thick [10]. The strength of the abraded specimen at the 50 % fracture probability $\sigma_{b(50\%)}$ was reduced to 40% of the polished specimens, which showed the important effect of surface roughness. Further, both the polished and abraded specimens tended to have slightly larger strength with thicker plates.

5.2.2. Delayed fracture strength characteristics

Since glass strength depends on time, long-delayed fracture strength is very important. The delayed fracture tests were conducted by applying a specified strain using a 4-point bending jig. The specimen was then left for a maximum of approximately 10^4 hours until it fractured. Figure 15 shows the delayed fracture strength of 5-mm thick polished specimens and, 5- and 10-mm thick abraded specimens, each normalized by the static strength $\sigma_{b(50\%)}$ of the respective specimens [10]. The delayed fracture strength characteristics normalized by the static strength show a degradation that

Fig. 14. Weibull distribution of static strength for polished and abraded specimens.

does not change with variations in the surface roughness or plate thickness. While the characteristics show a significant reduction for 10^2 hours, they show a gradual decrease for the rest of the time (displaying an asymptotic line of abraded specimens). In addition, the strength around 10^4 hours or more after the start of the test tends to be approximately 45% of the static strength. In Fig. 16, the fracture data of abraded specimens is classified into two groups based on the stress level after 10^2 hours ($\sigma_{(100hr)}$): high stress data (short-term fracture data) and low stress data (long-term fracture data), which are normalized by the strength $\sigma_{(50\%)}$ at a 50% fracture probability in order to show the results summed up by a Weibull distribution [11]. The dashed line in the figure indicates the probability distribution of the static strength normalized by strength $\sigma_{b(50\%)}$ at a 50% fracture probability. The distribution of the high stress data (the short-term fracture data) is similar to the low stress data (the long-term fracture data), and both data are close to the static

Fig. 15. Non-dimensional delayed fracture characteristics for polished and abraded specimens.

Fig. 16. Weibull distribution of nondimensional delayed fractures and static strength for abraded specimens.

strength distribution. Consequently, the irregularity of the static strength for abraded specimens can be considered to be a design index for the evaluation of strength against the delayed fracture of the CRT tube glass.

5.3. Evaluation of Tube Strength Reliability

The evaluation of tube stress is carried out without an implosion protection structure (vacuum stress) in the short term of the production process and on the final product with the implosion protection structure (vacuum stress being reduced by it's structure) in the long term. The standards for glass strength required in CRT design (delayed fracture strength characteristics for reliability) can be estimated by using the average delayed fracture strength characteristics and probability distribution of static strength characteristics in Section 5.2. As an example, the static strength and delayed fracture strength for abraded specimens at a 50% reliability are given in Table 2. The evaluation of the long-term reliability of a finished CRT tube, designed in an optimum manner through simulations, is carried out by using a reliability of 99.999% and a 10^5 hours delayed fracture strength.

6. CONCLUSION

The effects of atmospheric pressure and implosion protection structure on the stress and deformation of CRTs were investigated through experiments and simulations. In addition, the strength characteristics of glass and the long-term reliability of CRTs under atmospheric pressure and

implosion protection band tightening were evaluated. The conclusions can be summarized as follows:

- (1) The results of atmospheric pressure and tension band tightening analyses for CRTs showed close agreement with the experimental stress and deformation.
- (2) The highest tensile stress under atmospheric pressure was generated in the area from the panel face edge to the frit seal, along the minor/major axis. The stress and deformation due to atmospheric pressure can be reduced by tightening the implosion protection bands.
- (3) The implosion protection structure can be properly designed by using these results.
- (4) A CRT designed by using these simulation techniques and the strength characteristics of the CRT glass which are taken account of the surface roughness and the delayed fracture, should be guaranteed for long-term reliability (99.999%, 10^5 hours).

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Table 2. Static strength and delayed fracture strength for abraded specimens at 50% reliability.

Static strength (MPa)	Delayed fracture strength (MPa)		
	10 hr	10^3 hr	10^5 hr
32	18	15	13