Mechanical and thermal crack growth along the seal edge of cathode ray tube

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Abstract

This article describes a thermal stress boundary element analysis which was carried out to select a mechanical device that would innovate the frit salvage of cathode ray tubes (CRT). The panel and funnel of a CRT are fritted at the seal edge. To reuse a CRT the panel and funnel are separated by etching and then applied a thermal shock. This procedure is known as frit salvage. Current yield of the frit salvage success rate is about 61% which means that 39% of the components are lost and cannot be reused. The financial burden can be reduced if the salvage rate is improved through a better understanding of the thermal shock mechanism.

During thermal shock, a crack was observed to initiate at the end of the axes and traverses towards the corner along the seal end. A CRT is lost when the crack travels along the diagonal corner of the panel.

Therefore, a 3¼ inch diameter Yates hydraulic cylinder is used to apply a mechanical load on the diagonal skirt to prevent thermal failure along the diagonal corner. The crack's promoter along the seal edge is also used to protect thermal shock on the outer face panel near the heel radius in order to prevent thermal failure on the diagonal corner.

A mechanical analysis of the process has been performed and the stresses compared to identify which form of the process will ensure that the crack grows in the required direction. A preliminary study was also performed to simulate the crack growth process using a BEM model incorporating crack growth elements based on dual BEM. The stress intensity factors were predicted.

This application is an excellent example of the advantages of using the boundary element method in an industrial setting.

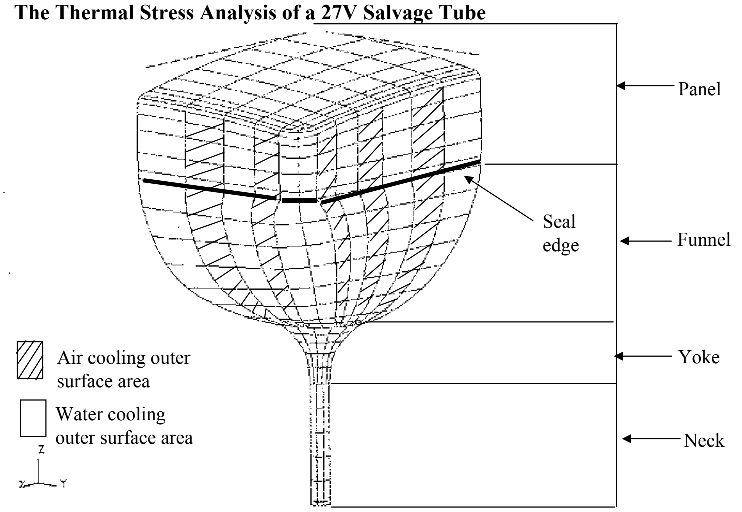

Fig. 1 Main features of 27 V tube with 3-D boundary element model.

1. Introduction

A CRT is constructed as a continuous envelope of glass. The main features of a CRT are shown in Fig. 1. Numerical techniques for the static stress analysis of engineering components have developed rapidly over the past decade, and today the two major alternatives are the finite method (FEM)[1] and the boundary element method (BEM).[2,3] Both techniques have been used to carry out a stress analysis of a 27 inch CRT. [4,5] The boundary element results achieve a high degree of accuracy even though the elements are located only on the surface. The BEM also allows remeshing of the surface easily in an extremely short period of time. In contrast, the finite element results appear to require a minimum of two eight-node brick elements in the thickness direction before the results approach the accuracy of the BEM analysis. The simplicity of carrying out a refined boundary discretization allows a more detailed convergence study and therefore ensures confidence in the stresses. In consequence, the boundary element model was easier and quicker to build, more accurate, and also has a much shorter modeling time than the finite model.

2. Problem

The panel and funnel of a CRT are fritted at seal edge as seen in Fig. 1. To reuse a CRT, the panel and funnel are first separated by etching the frit along the seal edge by using Nitric acid at 130°F. The glass is then cooled from 130°F to 60°F with water at 60°F in 50 s. During thermal shock, a crack was observed to initiate at the end of the axes and traverse toward the corner along the seal end. However, 33% of the CRT's are lost because of the crack traveling along the diagonal corner as shown in Fig. 2a.

In order to analyze the mechanism, which caused the crack. BEM was chosen resulting from its ease of use are its well known suitability for solving problems involving cracks and stress concentrations. [6] A thermal stress analysis was carried out using the commercial boundary element code BEASY. [7] Two planes of symmetry are assumed, allowing only one quarter of the full tube to be modeled. A heat transfer analysis was first carried out to determine the temperature variation throughout the CRT during thermal shock. A cooling rate of 84°F min $^{-1}$ was assumed to simulate the actual process of cooling from 130°F – 60°F in 30 s.

A thermal stress analysis was then carried out using the temperature solutions from the heat transfer analysis. All stresses in this paper indicate maximum principal tensile stress. The thermoelastic response of the CRT was analyzed using BEASY. For this study, an approximate solution was obtained by first determining the surface temperature distribution from a heat transfer analysis which included the volume source, and then applying that temperature portion of the solution for a thermal stress analysis. The assumption was made that the through thickness of the volume source is small, and that the term in the elasticity equations which considers the volumetric effects of the source temperature profile is negligible. This assumption is appropriate since the CRT has a comparatively thin section.

A quarter symmetry three-dimensional boundary element model of the CRT shown in Fig. 1 consisted of 542 continuous quadratic elements and has 8374 equations. The CRT is assumed homogeneous and isotropic with the following glass material constants (Corning Glass code 9061):

Young's modulus 10.07 E + 6 psi
Poisson's ratio = 0.23
Thermal conductivity = 1.4 E-5 BTU/ins $^{-1}$°F
Thermal expansion coefficient = 5.5 E-6 in/in °F
Reference temperature = 68°F
Volume Source = 2.854 E-3 BTU/in ^{3} s^{-1}
Heat transfer coefficient of water with the ambient temperature 60°F at outer glass surface = 1.543 E-5 BTU/in ^{2} s^{-1}°F
Heat transfer coefficient of air with ambient temperature 130°F at inner glass surface = 2.55 E-5 BTU/in ^{2} s^{-1}°F
Heat transfer coefficient of air with ambient temperature 60°F at outer glass = E-5 BTU/in ^{2} s^{-1}°F

A previous study has been performed for frit salvage improvement of cathode ray tube with mechanical crack initiation[8] and thermal crack initiation[9].

A 3¼ inch diameter Yates hydraulic cylinder is also used to apply a mechanical pressure load of 1533 psi on the diagonal skirt to prevent stress failure along the diagonal corner, i.e., to promote a crack along line ABC instead of line ADEC in Fig. 2a. The hatched area in Fig. 2a designates the location of the mechanical pressure load.

The rubber seal edge crack promoter was attached to the outer face panel near the heel radius as shown in Fig. 2b. The dominant stresses are indicated by the contour stripes showing the principal stresses. The principal stresses should be perpendicular to the seal edge.

Two different heat transfer coefficients were prescribed on the outer glass surface of the CRT as shown in Fig. 1 when the crack's promoter along the seal edge is simulated. On the hatched outer surface area the heat transfer coefficient of air was prescribed while the unhatched area water was used. When the crack's promoter along the seal edge is not simulated the heat transfer coefficient of the outer surface is water.

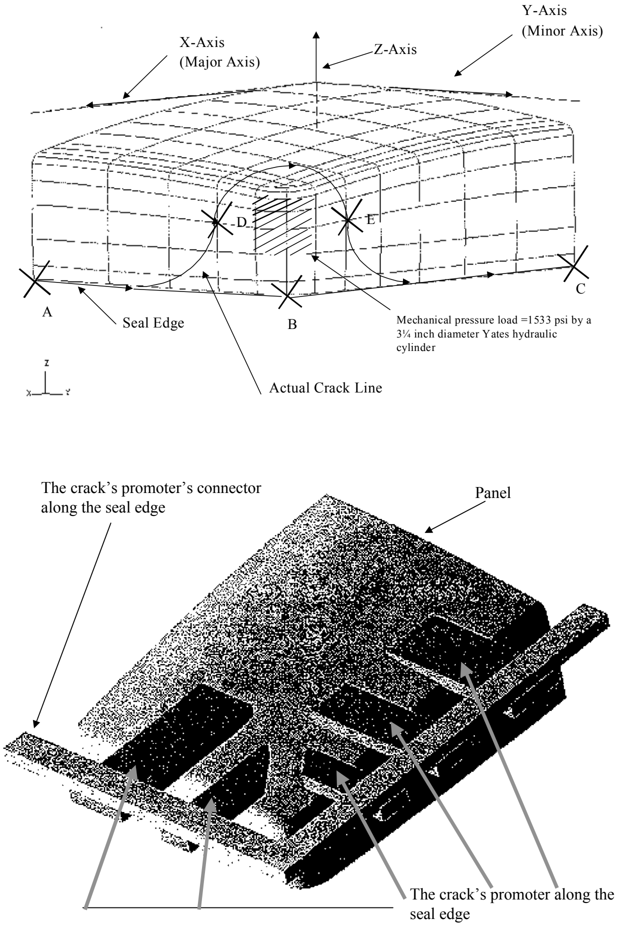

Fig. 2. (a) Detailed description of the panel. (b) The crack's promoter along the seal edge with panel

3.1 Thermal stress analysis results

The temperature solution over the outer glass surface is shown in Fig. 3. The entire outer surface is subjected to a temperature of 60°F. The temperature variation over the inner glass surface is shown in Fig. 4. The temperature of the inner face panel is 119°F and gradually decreases to 60°F at the neck area. This temperature variation is very reasonable since the thickness of the face panel is much larger than that of the neck.

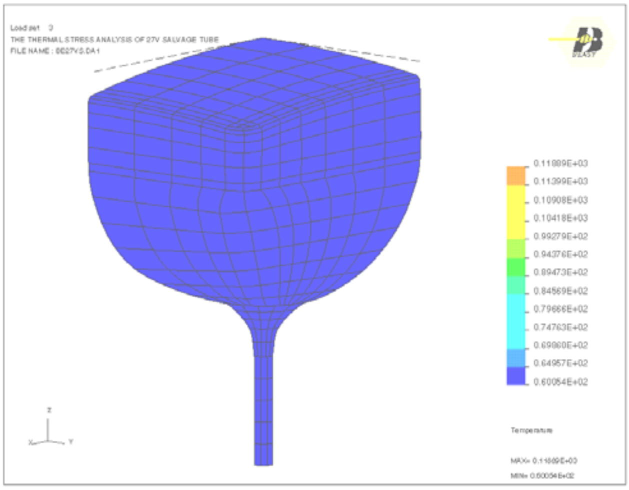

Fig. 3. Temperature solutions of outer glass surface.

The principal stress solutions of the outer glass surface is tensile, as shown in Fig. 5. The principal stress solution of the inner glass surface is comprehensive and the figure is not shown because of the whole compression uniformity of the surface. The crack will always begin on the outer glass surface since the stress is tensile and glass is a very brittle material. Fig. 6 shows an enlarged view of the stresses over the outer panel surface since this is the crack growth region. A detailed description of the outer panel shown in Fig. 2a indicates various locations (A-E) for studying crack growth. The results of the stress analysis of the panel at various outer surface locations for the salvage tube with and without the crack's promoter along the seal edge can be seen in Table 1.

The + and – signs in Table 1 indicate the amount of increased and decreased principal stress, respectively, on the salvage tube with the crack's promoter along the seal edge. The principal stress directions on the outer glass surface are shown in Fig. 7. The crack starts at point A (on major axis), (see also fig. 2a) which has the maximum stress value (3323 psi), and proceeds along the seal edge. The crack then changes direction toward point D where the stress is 524 psi greater than point B. This is consistent with Fig. 7 since the crack propagates perpendicular to the principal stress direction at point D. The crack then continues to propagate towards point E, then proceeds to the seal edge, then along the seal edge and finally along the seal edge to point C. This result closely matches the frit salvage process at Philips Display Components Company.

A thermal shock is applied by pouring water at 60°F on the outer centre face of the panel. Water flows over the entire outer surface of the CRT except for the hatched area of the panel and funnel as shown in Fig. 1. Water does not flow on the hatched surface area since it is diverted by the crack promoter along the seal edge as shown in Fig. 2b. However, water does flow on the non-hatched surface areas through the effects of gravity. (Note, the effect of water flow path can be clearly visualized in Fig 8 where distinct thermal stripes can be seen.)

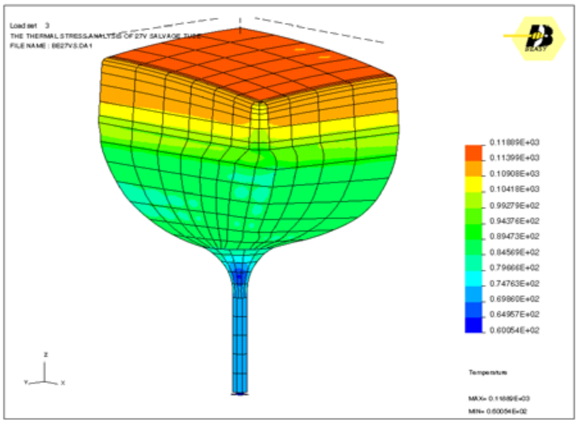

Fig. 4. Temperature solutions of inner glass surface.

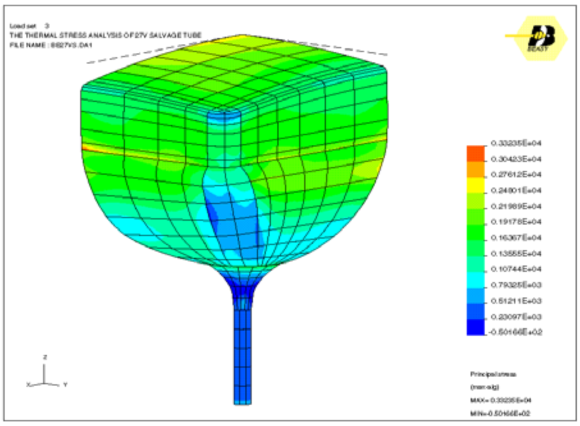

Fig. 5. Principal stress solution of outer glass surface.

It is an essential requirement of the frit salvage process that the stresses on the outer surface near the seal edge are perpendicular to the required crack direction.

The panel and funnel were included as an air-cooling portion, while air cooling on the yoke and neck surface area below the corner panel pullout protector, was neglected. This assumption is reasonable since the effects of this surface area on the seal edge is negligible because the large distance of the yoke and neck from the seal edge. The temperature solution of outer glass surface with mechanical and thermal crack initiation is shown in Fig. 8. Two kinds of stripes' temperatures on the side of the panel exists. The relative higher temperatures of the stripes with approximately 107*F by the air's cooling, are located below the crack's promoter along the seal edge. The relative lower temperatures of stripes with 60°F by the water's cooling are located, except below the crack's promoter, along the seal edge. The temperature solution of inner glass surface with mechanical and thermal crack initiation is shown in Fig. 9.

The temperatures of the panel and funnel below the crack's promoter along the seal edge are relatively higher than the rest of it (Figs 8 and 9).
The principal stress solutions of outer glass surface with mechanical and thermal crack initiation are tensile (Fig. 10).

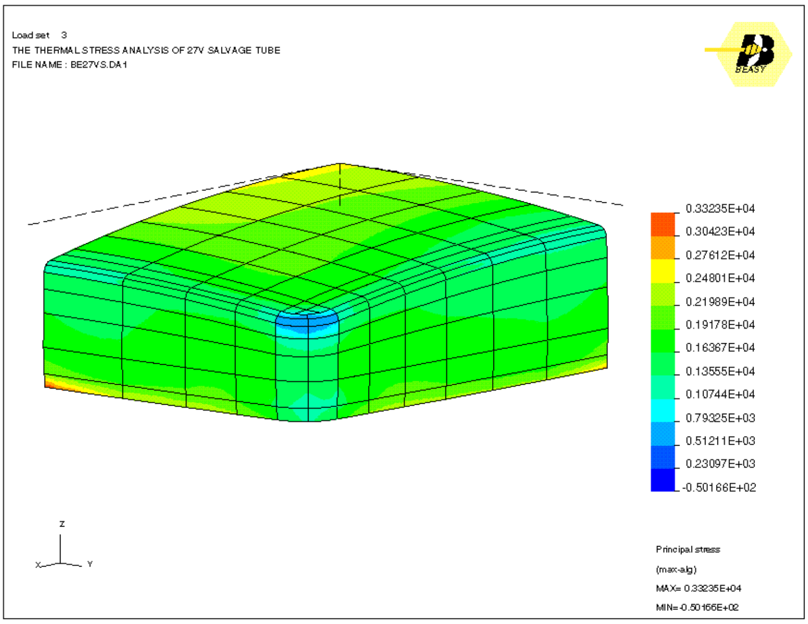

Fig. 6. Principal stress solution of outer panel surface.

Table 1. Principal stress comparison of the outer panels between salvage tube and salvage tube with mechanical and thermal crack initiation

Mesh point locations (Fig. 2a)	A	B	C	D	E
Mesh No.	1618	1657	1680	1461	1567
The stress of salvage tube (psi)	3323	1275	2889	1799	1768
The stress of salvage tube with mechanical and thermal crack initiation (psi)	3823	1472	796	1461	1626
Change in stress due to salvage process (psi)	+500	+197	-2093	-338	-142

The principal stresses on the inner glass surface with mechanical and thermal crack initiation are compressive and generally uniform.

The principal stresses on the outer panel surface with mechanical and thermal crack initiation can be seen in Fig. 11.

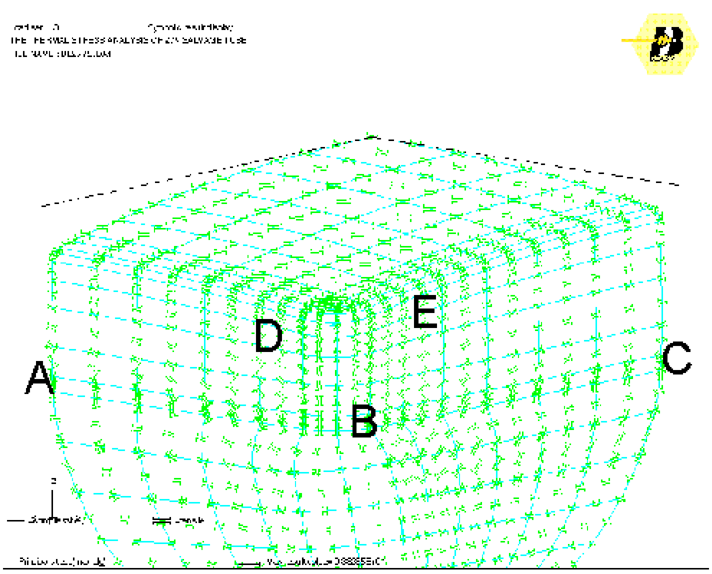

Fig. 7. The principal stress directions of outer glass surface.

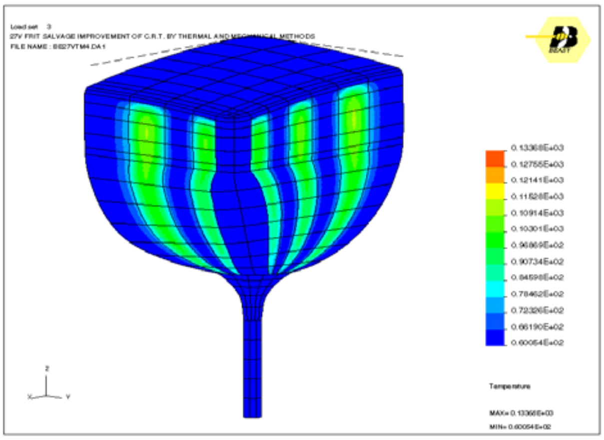

Fig. 8. Temperature solutions of outer glass surface with mechanical and thermal crack initiation

The analysis of the frit salvage process with mechanical loads reveals two significant features:-

- The stress at point D is reduced by 338 psi and at E by 142 psi thus significantly reducing the maximum principal stress;
- The maximum principal stress along the seal is increased, eg, by 197 psi at B.

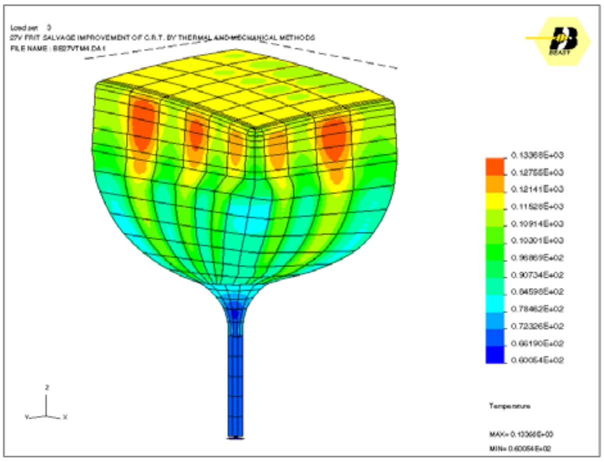

Fig. 9. Temperature solutions of inner glass surface with mechanical and thermal crack initiation

Fig. 12 shows the principal stress directions of the outer glass with mechanical and thermal crack initiation. These principal stresses' directions have two features:-

- The dominant higher stripe's principal stresses' directions along the seal edge by the water cooling, are perpendicular to the seal edge. The previous directions of principal stresses along the seal edge (Fig. 7), were not perpendicular to the seal edge;
- The previous principal directions of stresses of D and E, which was approximately 135° and 45° respectively, with the inclination in respect to the seal edge, have been changed to perpendicular to the seal edge. This will prevent the crack along the seal edge propagating from points D-E.

These results above are due to the thermal crack initiation. Resulting from the features above, the crack will start at point A which has the maximum principal stress, then follow a path normal to the dominant higher principal stresses along the seal edge and end at point C.

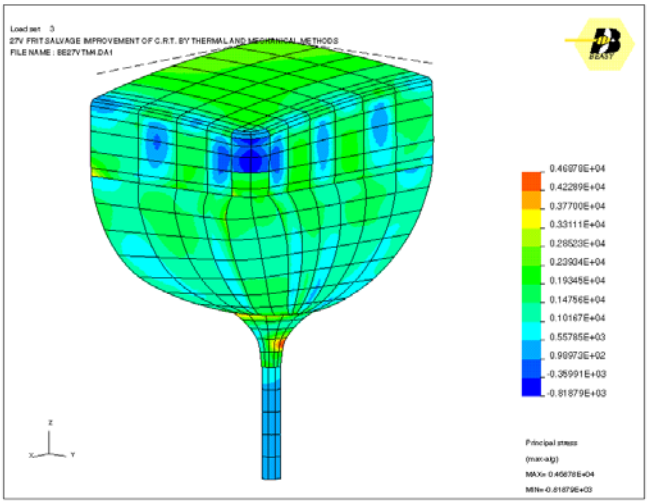

Fig. 10. Principal stress solutions of outer glass surface with mechanical and thermal crack initiation

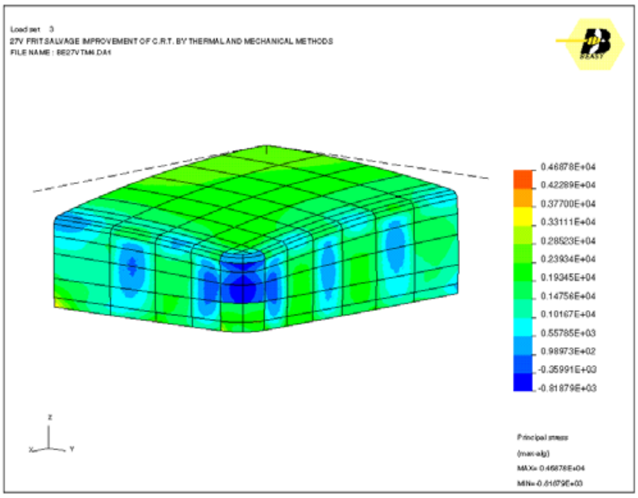

Fig. 11. Principal stress of outer panel surface with mechanical and thermal crack initiation

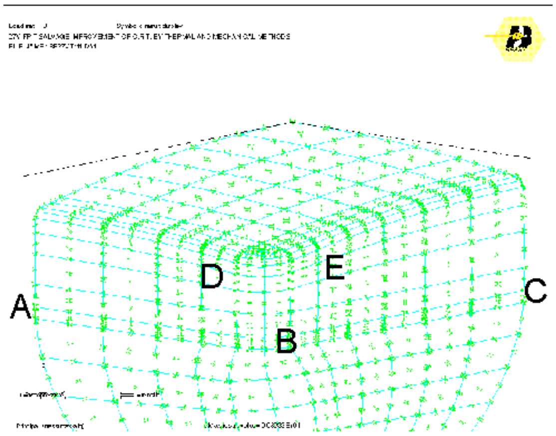

Fig. 12 Principal stress directions of outer glass surface with mechanical and thermal crack initiation

3.1 Crack growth analysis results

In order to obtain a more accurate prediction of the crack growth a model was prepared incorporating an initial crack along the seal

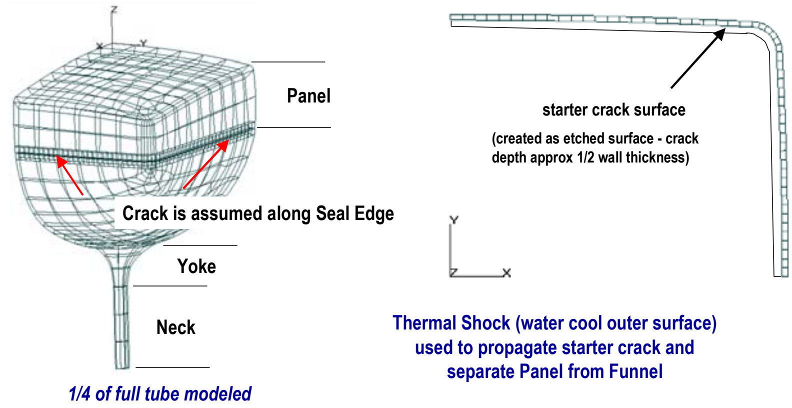

Fig 13 Crack growth model showing the initial crack mesh used to predict the SIF

edge. The objective of the model was to determine the stress intensity factors and hence the crack growth direction. The model and mesh is shown in Fig 13.

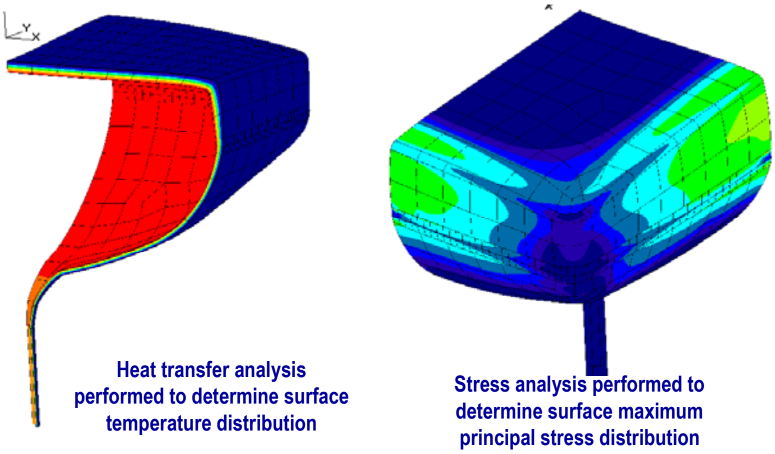

Fig 14 Thermal and thermal stress analysis of the tube incorporating the crack

Fig 14 shows the predicted temperature distributions and the stress values induced in the tube under the applied thermal loads representing the process. In this analysis no attempt has been made to simulate the actual crack growth the main purpose is to compute the stress intensity factors which indicate the direction the crack will grow and the rate of growth of the crack.

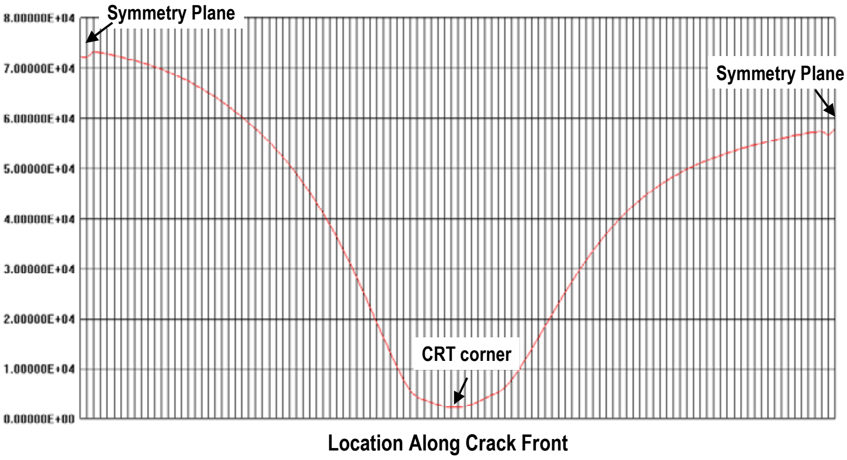

Fig 15 Distribution of the stress intensity factor along the seal edge

Fig 15 shows the distribution of the stress intensity factor and clearly indicates the relative speed of growth of the crack. By examining the all the modes of the stress intensities the growth direction can be predicted using a minimum strain energy criteria.

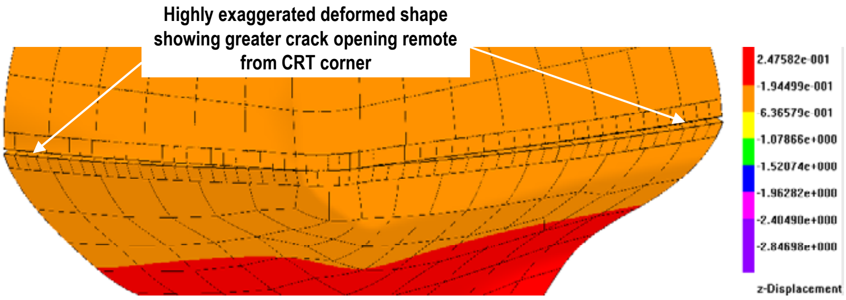

Fig 16 Exaggerated deformed shape of the tube clearly showing the crack

Figure 16 shows the exaggerated deformed shape of the tube clearly showing greater crack opening remote from CRT corner.

4. Conclusion

A 3¼ inch diameter Yates hydraulic cylinder is used to apply a mechanical load on the diagonal skirt to prevent thermal failure along the diagonal corner. The crack's promoter along the seal edge is also used to protect thermal shock on the outer face panel near the heel radius in order to prevent thermal failure on the diagonal corner. The resultant stresses have four features. The maximum principal stresses on the diagonal corner have decreased significantly. Secondly, the principal stresses along the seal at the diagonal increase. Thirdly, the directions of the dominant high stresses at the seal edge through the crack's promoter were changed perpendicular to the seal edge. Finally, the stresses' directions on a diagonal corner have also been changed to be perpendicular to the seal edge. Consequently, the crack continues to traverse along a path normal to the principal stress at the seal edge as required for a successful frit salvage process.

An initial study of the crack growth has provided preliminary data on the crack growth direction and crack growth rate.

The Boundary Element Method has demonstrated the accuracy and sensitivity to simulate the frit salvage process

Further studies are planed to simulate the actual crack growth process using the BEASY automatic crack simulation procedure and to further optimize the manufacturing process.

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