Non-Athermal Potting of Optics

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ABSTRACT

Historically lenses and windows on many military production programs, are potted (elastomerically bonded), often with less than theoretical athermal potting gaps. Actual gaps may vary by factors of 2 to 4 less than ideal for athermal potting. Yet these military systems have passed rigorous qualification tests and seem to work adequately. Are problems lurking in the extremes of cold or hot for which MTF measurements are not typically done? Are typical stress levels high enough to impact optical performance? This manuscript will address these issues.

Finite element models will be used to examine a number of representative germanium optics to show to what extent these elements are affected by non-optimal potting gaps. Cases include a convex-concave lens, a concave-concave lens, and a convex-convex lens. All the optical elements will be potted in aluminum housings.

Keywords: Potting, mounting stress, lens, athermal, elastomeric mount

1. INTRODUCTION

Tactical military optical systems for targeting, surveillance, and situational awareness typically use potted (elastomeric) mounts for optical elements. Systems designed by the author are typically infrared systems in the long wave and mid wave regimes. Optical materials are therefore infrared transmitting materials. Housings are usually made of aluminum. The potting materials are silicone rubber compounds. This method is typical for all tactical uses such as: man portable, wheeled vehicle, tracked vehicle, fixed wing, or rotary wing. Due to platform dynamics, stiffly mounted lenses reduce image jitter.

Finite element models examine a number of representative germanium optics to show the effect of non-athermal potting gaps. Cases are a concave-concave lens , a convex-concave lens, and a convex-convex lens. All optical elements are potted in aluminum housings. FEM analysis results include maximum stress at high temperature, 1st resonant mode frequencies, and typical mode shapes. Potting gaps range from 1 X athermal to .065 X athermal.

2. LENS CONFIGURATIONS

Typical gap calculations only consider the diameter of the optical element. Lens configuration affects the stiffness of the lens with respect to its mount, and the stresses created . Figures 2-1, 2-2, and 2-3 show physical configuration and sizes.

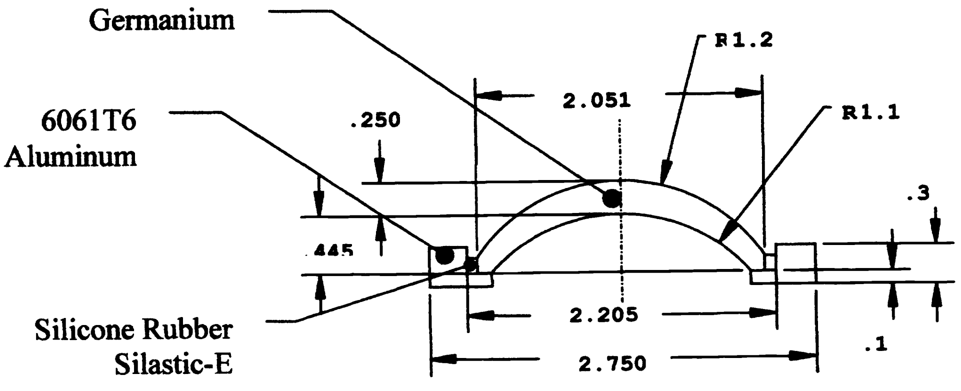

Figure 2-1: Convex-Concave Lens configuration.

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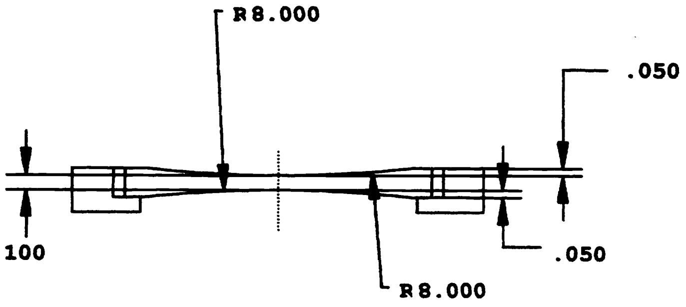

Figure 2-2: Concave-Concave lens configuration

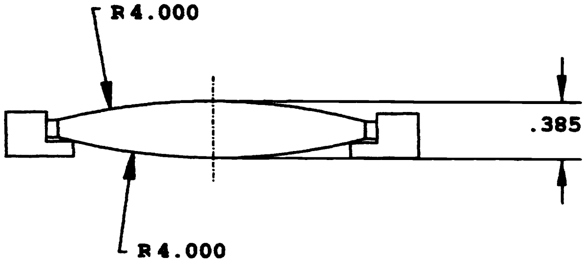

Figure 2-3: Convex-Convex lens configuration

3. ATHERMAL POTTING GAP CALCULATION

From Bayar (1981)[1].

$$t_e = \frac{D_G(\alpha_m-\alpha_g)}{2(\alpha_e-\alpha_m)} \qquad (1)$$

t_e = .077 inch = radial thickness of potting
D_G = 2.051 inch = lens diameter
α_m = 23E-6 C^{-1} = mount coefficient of expansion
α_g = 6.0E-6 C^{-1} = lens coefficient of expansion
α_e = 248E-6 C^{-1} = potting coefficient of expansion

Note that the above equation derivation does not include the effects of gap length, Poisson's ratio, or Young's modulus. The simplified assumptions to derive the above equation do not really yield a "stress free" lens mount.

4. FINITE ELEMENT MODEL (FEM) ANALYSIS METHODOLOGY

A Raytheon internal FEM code is utilized. Linear and isotropic material properties are used. Axisymetric 2D models approximate the stress distribution and first dynamic mode of the lens systems. Plate element models predict higher order mode shapes of the lens system. Inherently, axisymetric 2D models cannot illustrate non-axisymetric modes. For the stress calculations, the 2D system is restrained on the lens axis. For the dynamic modes, on-axis restraints are free, the external perimeter of the aluminum ring is constrained.

Typical military systems have operational ambient conditions[4] that range from –32 C to +52 C. The systems often have internal and external heat loads that may increase temperatures of housings and lenses another 18 C. The models yield the same absolute stress levels whether the temperature delta is positive or negative. For visualization reasons, positive deltas yield better visual results when the displacements are exaggerated. Each node is given a temperature of +50 C. All material definitions have 0 C stress free temperature conditions.

Material properties for each material used in the FEM models are tabulated as follows in Table 4-1. Properties come from a number of sources. Young's modulus for silicone rubber came from an unpublished measurement, this value is higher than shown in textbook such as Yoder[2].

Property	6061T6 aluminum	Germanium	Silicone Rubber (Silastic-E)
Young's Modulus (lb/in^2)	10,000,000	14,970,000	600*
Coefficient of thermal expansion (in/in/C)	.000023	.0000058	.000248[3] **
Poisson's ratio	.33	.278	.49***
Density (lb/in^3)	.098	.192	.047

*unpublished measurement

** from Raytheon process

*** maximum value that FEM code will run

Table 4-1: Material Properties from Yoder[2] (unless otherwise denoted)

5. FEM RESULTS

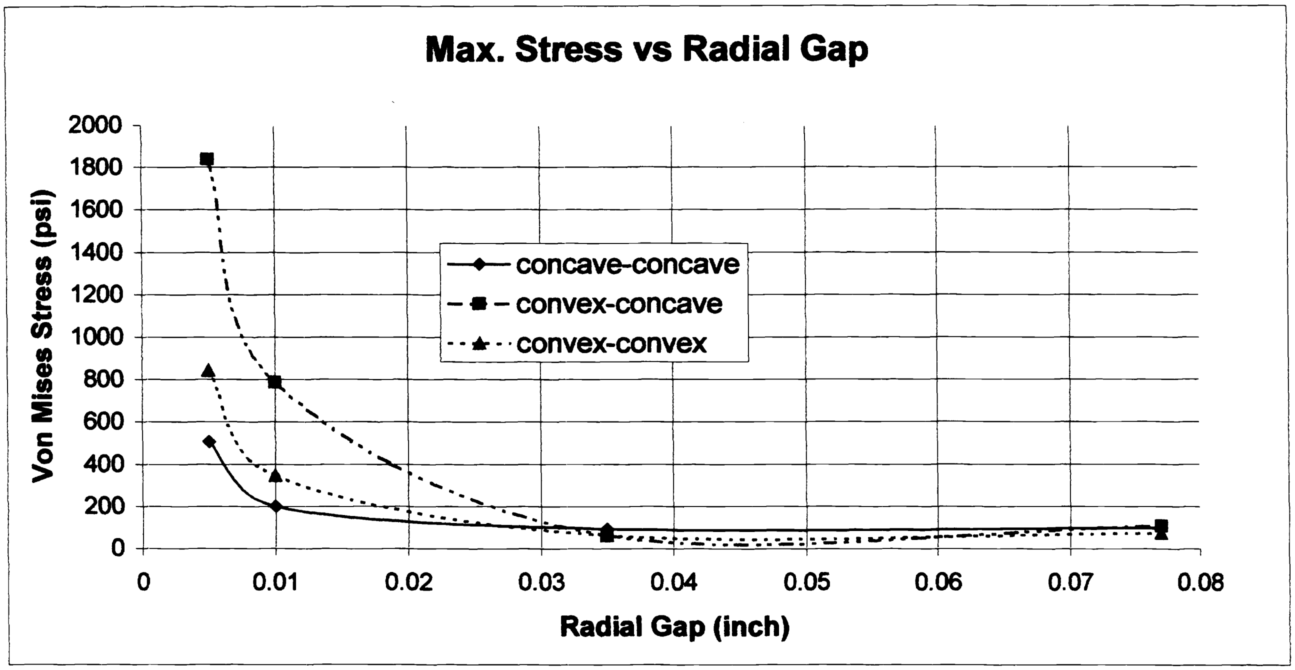

Figure 5-1: Maximum Von Mises stress in the lens as a function of radial potting gap

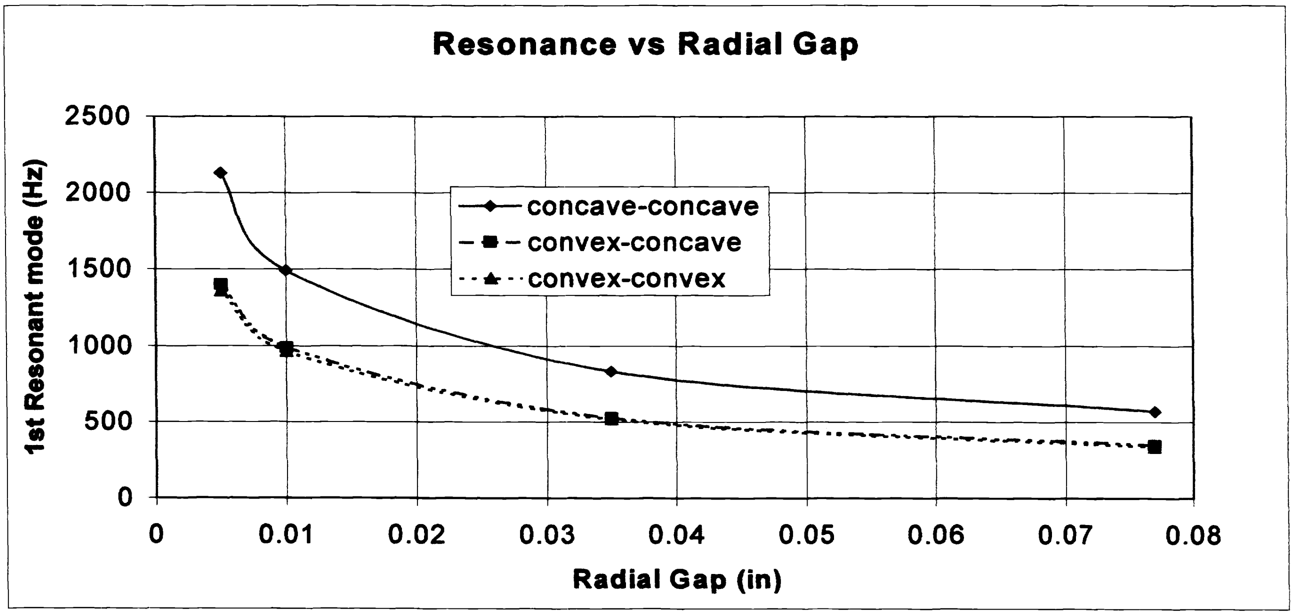

Figure 5-2: First lens resonance as a function of radial potting gap

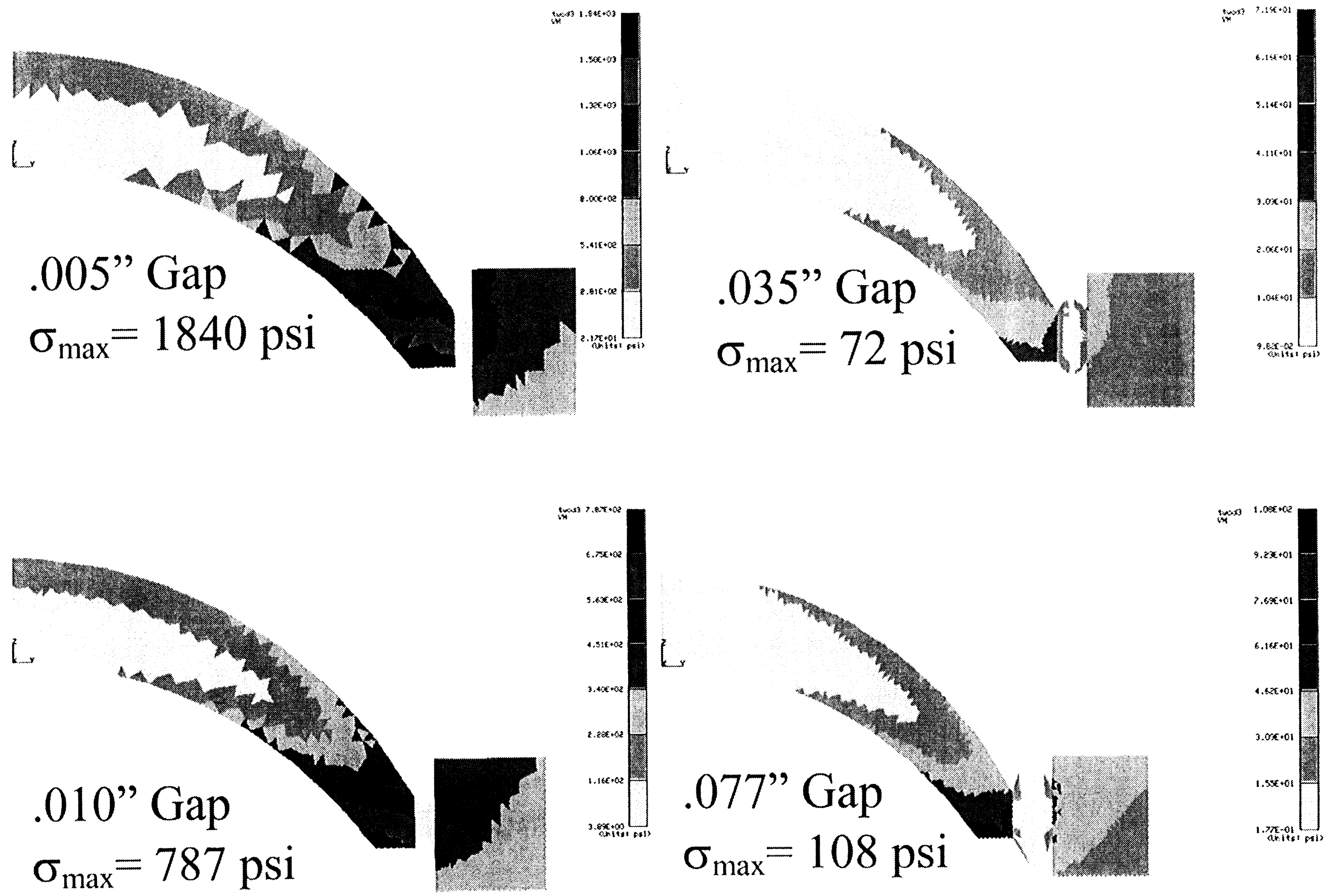

Figure 5-3: Convex-Concave configuration stress results

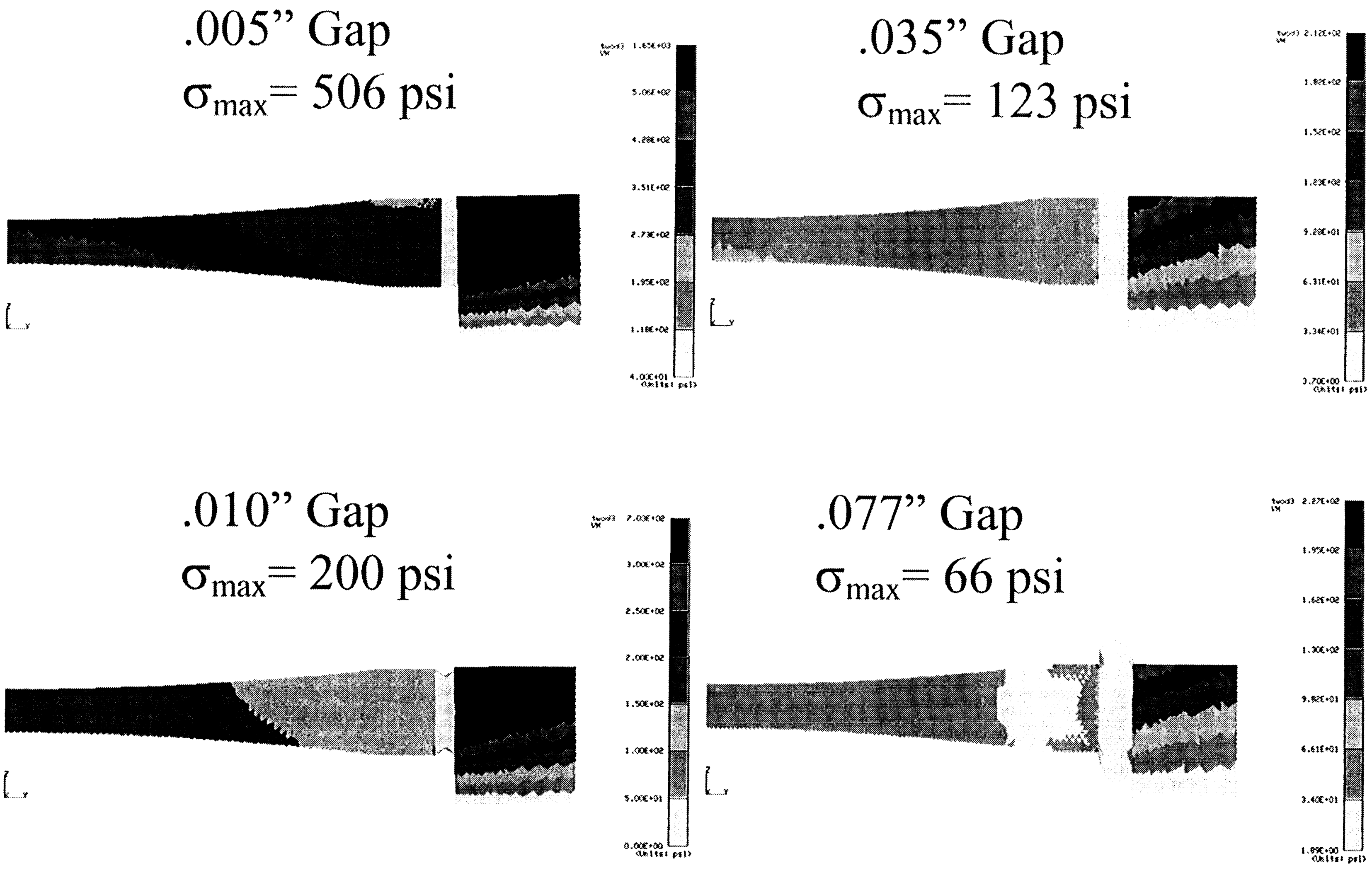

Figure 5-4: Concave-Concave configuration stress results

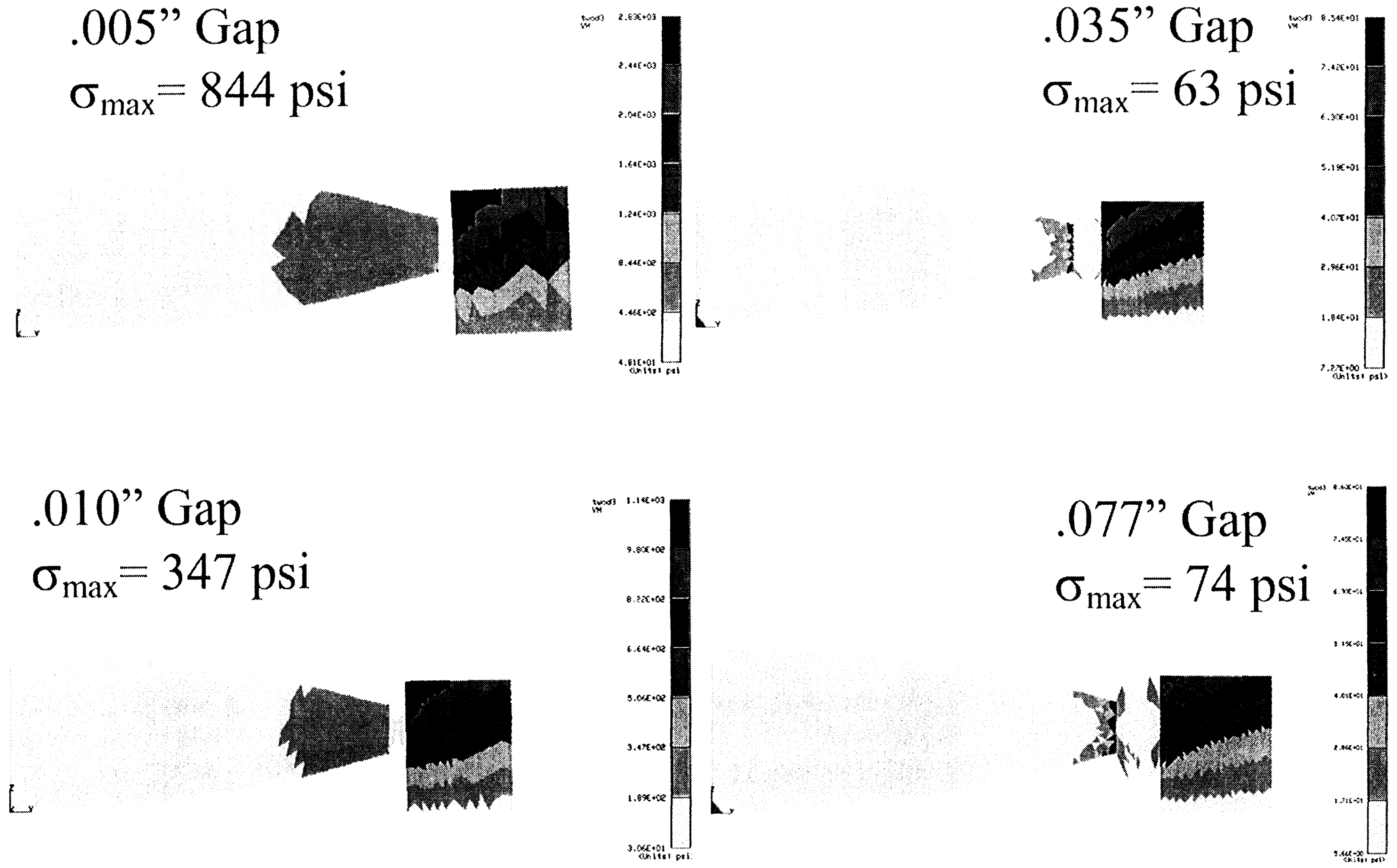

Figure 5-5: Convex-Convex configuration stress results

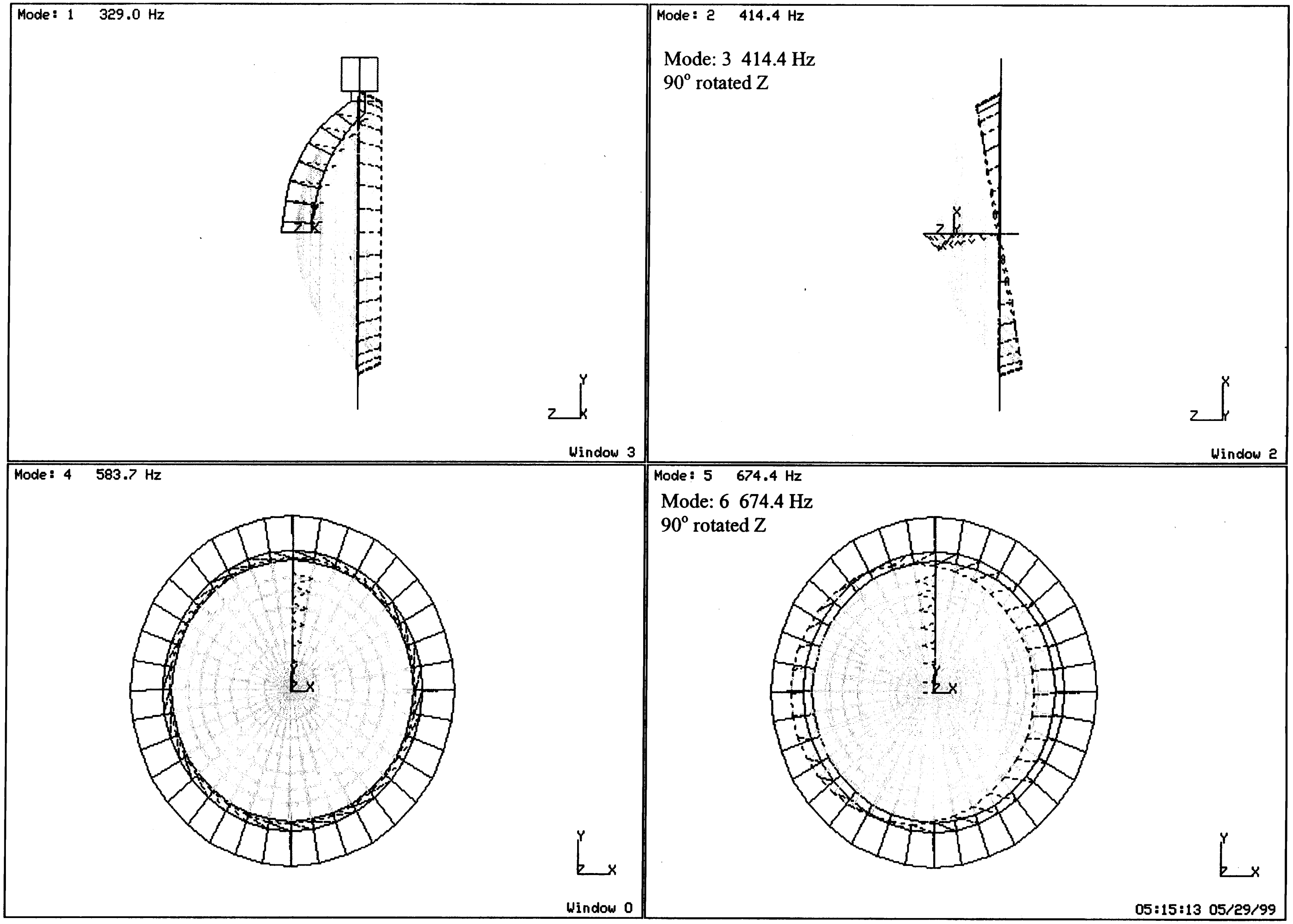

Figure 5-6: Mode shapes for the Convex-Concave configuration

6. SUMMARY

This analysis indicates latent design defects caused by improper optics potting on legacy hardware are unlikely. Opto-mechanical engineers everywhere can sleep restfully again.

Gaps sized per equation (1), do not result in the lowest stress possible. However, the stress is still quite low and would not result in a bond line failure. In dynamic environments, smaller gaps reduce image jitter, and optical stresses are still quite low, possibly lower than the athermal gap case. Stress in the optical elements is strongly dependent on the lens configuration.

The athermal gap equation is certainly still useful. However, a rule of thumb guideline might be developed for what fraction of athermal gap is still good without resorting to a FEM analysis. For the aluminum/germanium/silicone combination, potting gaps for stiff lenses like a convex-convex or concave-concave, could be as little as 1/8 the athermal gap. For a less stiff lens, like the convex-concave, the gap could be ¼ the athermal gap. More work is necessary to look at different lens sizes and other mounting materials to see if the same rule of thumb could be used.

ACKNOWLEDGMENTS

Bob Morgan and Bill McDonald of the Raytheon Sensors and Electronics Systems Applied Mechanics Group reviewed modeling techniques and provided sanity checks.

REFERENCES

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3. Raytheon Internal Process Specification, F-445(method 3), equivalent to MIL-S-23586, Type II, Class 2, Grade B-2
4. MIL-STD-910E