

## Estimation of handling stresses in a 4 m Zerodur blank with the finite element method

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Dedicated to Dr. H. J. Klein on the occasion of his 65th birthday

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During handling of large Zerodur blanks for astronomical applications, the risk of a break due to an improper procedure is rather high. Using the example of a 4 m Zerodur blank produced by spincasting, this paper demonstrates that the finite element method can be used to estimate the handling stresses in advance. In this way, critical situations can be avoided.

Two typical situations are investigated: the position of the blank on 4 or 2 support points, and the moment where the blank is standing vertically during a turning movement. Only static stresses produced by gravity are computed (no further accelerations). The results show the magnitude and distribution of the resulting first principal stresses.

### Abschätzung von Spannungen beim Handling einer 4-m-Zerodur-Scheibe mit der Finite-Elemente-Methode

Beim Handling von großen Zerodur-Scheiben, wie sie etwa für astronomische Anwendungen produziert werden, können bei unsachgemäßer Handhabung leicht Spannungen entstehen, die zum Bruch führen. Die Arbeit zeigt am Beispiel einer nach dem Schleuderverfahren hergestellten gewölbten 4-m-Scheibe, wie die Spannungen beim Handling mit der Finite-Elemente-Methode abgeschätzt und damit kritische Situationen vermieden werden können.

Es werden zwei typische Zustände untersucht, und zwar die Lagerung der Scheibe auf vier bzw. zwei Unterstützungspunkten (mit verschiedenen Anordnungen) sowie eine Situation, in der die Scheibe während eines Drehvorganges senkrecht steht. Es werden nur Spannungen berechnet, die sich statisch durch das Eigengewicht einstellen (keine Beschleunigungseffekte). Die Ergebnisse zeigen die Größe und Verteilung der resultierenden Spannungen.

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### 1. Introduction

There is a great interest in optical astronomical mirror systems with constantly growing diameters and shrinking thicknesses. This leads to an increasing handling risk for the manufacturer of the mirror blanks. The present paper will show that the method of finite elements has the potential to compute the handling deformations and stresses to be expected with relatively small effort. Such results are of great value in estimating the risk of a break. By applying these methods an adaptation and optimization of the handling tools is possible. This article presents only some idealized situations. In real applications the effort to get realistic and reliable results will be much greater. For a good instruction to the Finite Element (FE) method see [1].

### 2. Computer-hard- and software used

All computations were done on a HP9000/350/UNIX workstation with the FEMFAM-software-package (licensed by Kernforschungsanlage Jülich). The amount of time for preparing, doing and graphically representing the results of the computations for the load cases was about 4 d. As always in contemporary FE packages, the preparation of the computations is the most time-consuming factor (modeling of the geometry

and of the element mesh, formulation of the boundary conditions). The computing time for each one of the 3 load cases on the HP machine was only about 15 min (with the FORTRAN version of the software).

### 3. Description of the example geometry

A Zerodur mirror blank, produced by the new spincasting process is considered. The diameter of the blank is 4.1 m, the thickness is only 0.11 m, the radius of curvature is 14 m.

For the FE computations this blank is divided into 112 elements (figure 1). Each of these 3d elements is shaped like a cube with curved edges. The elements are isoparametric, represented by 20 knots each, which means quadratic interpolation of the geometry and of the deformations. Thus, good results are achieved with relatively few elements. Because of symmetry only one half of the blank is modeled. The 112 elements were produced with the FEMFAM mesh generator from a single superelement.

### 4. Material parameters

In the FE calculations the following material parameters for Zerodur were used: the density is 2530 kg/m<sup>3</sup>, the modulus of elasticity is 80 GPa, and the Poisson ratio is 0.22. The weight of the blank is thus only about 3.5 t.

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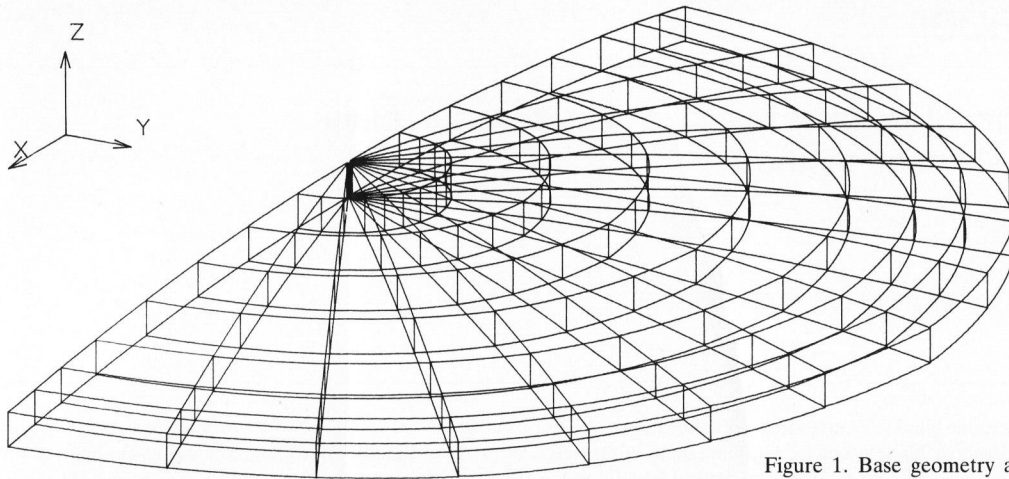


Figure 1. Base geometry and finite element division.

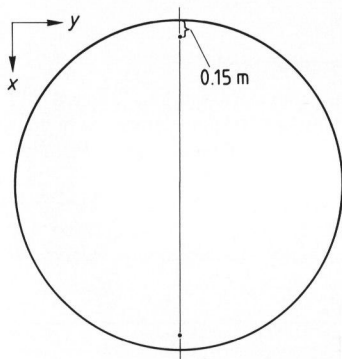


Figure 2. Load case 1: blank positioned horizontally, 2 support points.

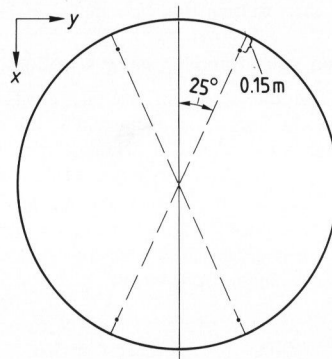


Figure 3. Load case 2: blank positioned horizontally, 4 support points.

### 5. Load cases

Three idealized load cases are presented. Only static deformations and stresses caused by gravity are computed, the influence of other accelerations and of the handling tools is neglected. In the first two cases the blank has just been turned around after spincasting and cooling (the convex side is up), and is positioned on a support frame. The stresses in the blank which are produced by a (idealized) 2 and a 4 point support are investigated. Figure 2 shows in schematic form the supporting points for the 2 point case, figure 3 is the analogue for the 4 point case. Both figures are seen from above (in negative z direction). In the third case (figure 4) the blank is just standing vertically during a turning movement. For this computation all 8 edge points of the lowest element were assumed to be fixed in space (see the arrow in figure 4).

### 6. Results

The results of the three load cases are presented in a very compact and shortened form, only to illustrate the principles.

For the manufacturer's handling problem the tension stresses are the most significant ones. In all three cases the computations show that the first

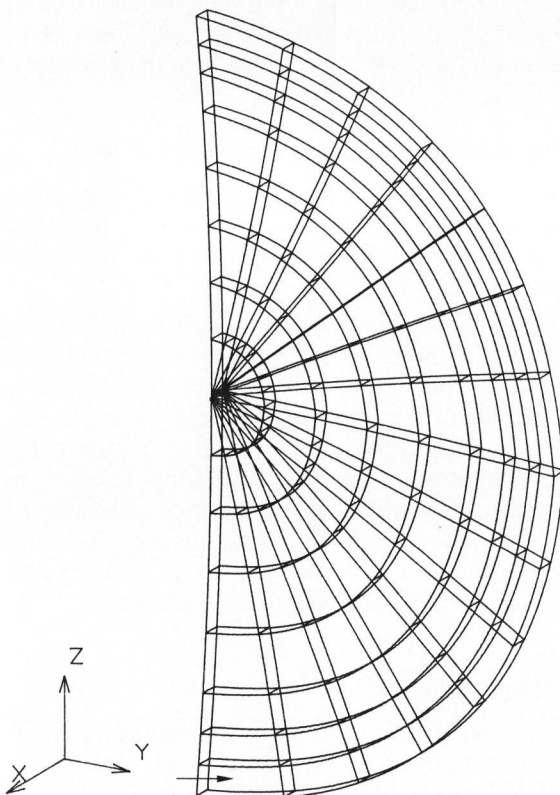


Figure 4. Load case 3: blank positioned vertically, 8 fixed points.

Figure 5. Load case 1: first principal stress.

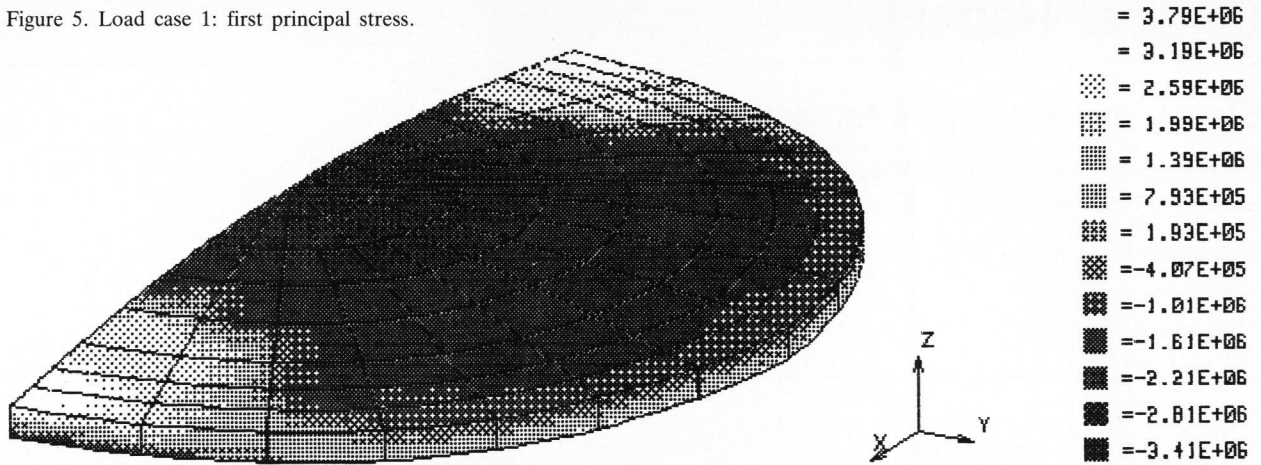


Figure 6. Load case 2: first principal stress.

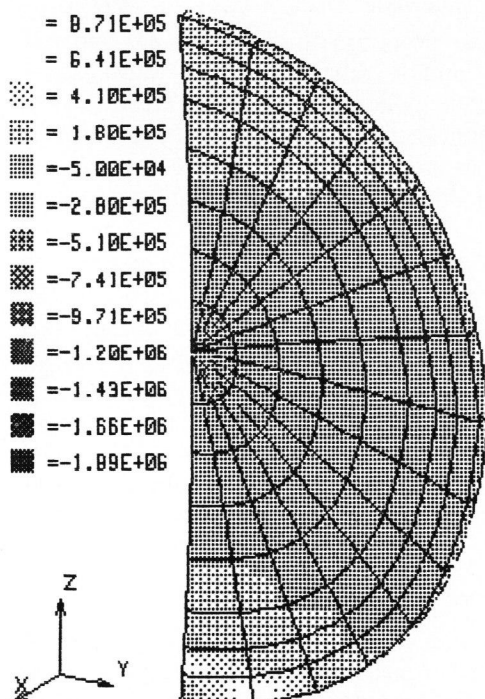
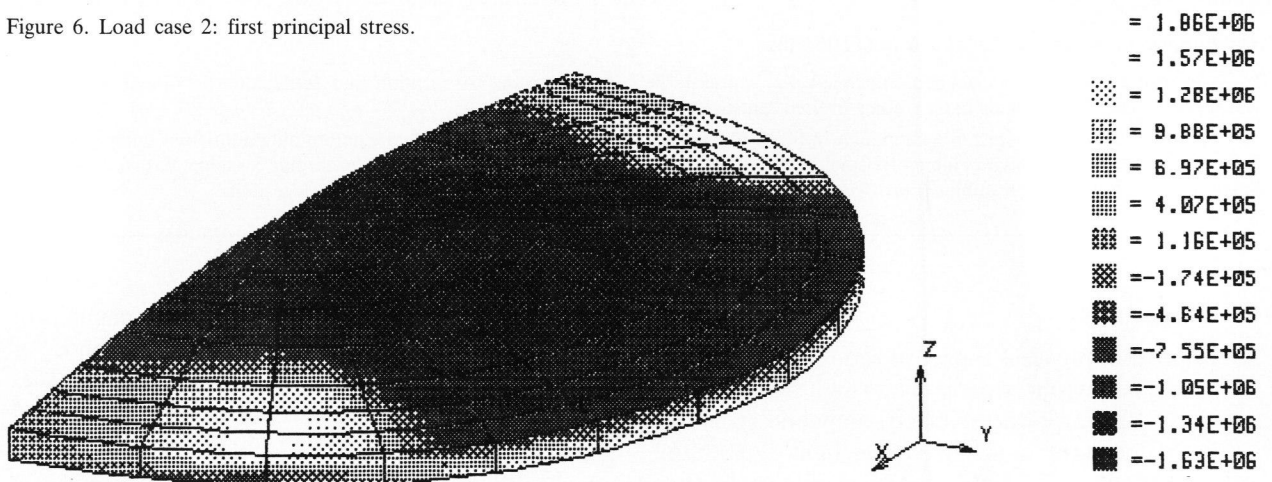


Figure 7. Load case 3: first principal stress.

principal stress is dominant in this regard. Therefore, only the distribution and magnitude of this stress component is presented.

Figure 5 contains the results for load case 1 (2 point support), figure 6 those for load case 2 (4 point support), and figure 7 those for load case 3 (vertically positioned blank). In load case 1, there is roughly a 4 N/mm<sup>2</sup> tension stress on the upper side of the blank, just above the 2 support points. In load case 2 only one half of this value is reached, also just above the support points. The value of 4 N/mm<sup>2</sup> is near the critical region, where a break is very probable. That means that a situation as in load case 1 should be avoided, the blank has to be supported in 4 (or better more) symmetrically distributed points. In load case 3 the greatest tension stress is below 1 N/mm<sup>2</sup> which means that the blank is sufficiently structurally stable to stand vertically if the lowest part of the blank is fixed in space.

7. Reference

[1] Huebner, K. H.; Thornton, E. A.: The finite element method for engineers. 2nd ed. New York: Wiley 1982. 89R0018