BEASY used for Optimization of Rotor Stress

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ABSTRACT

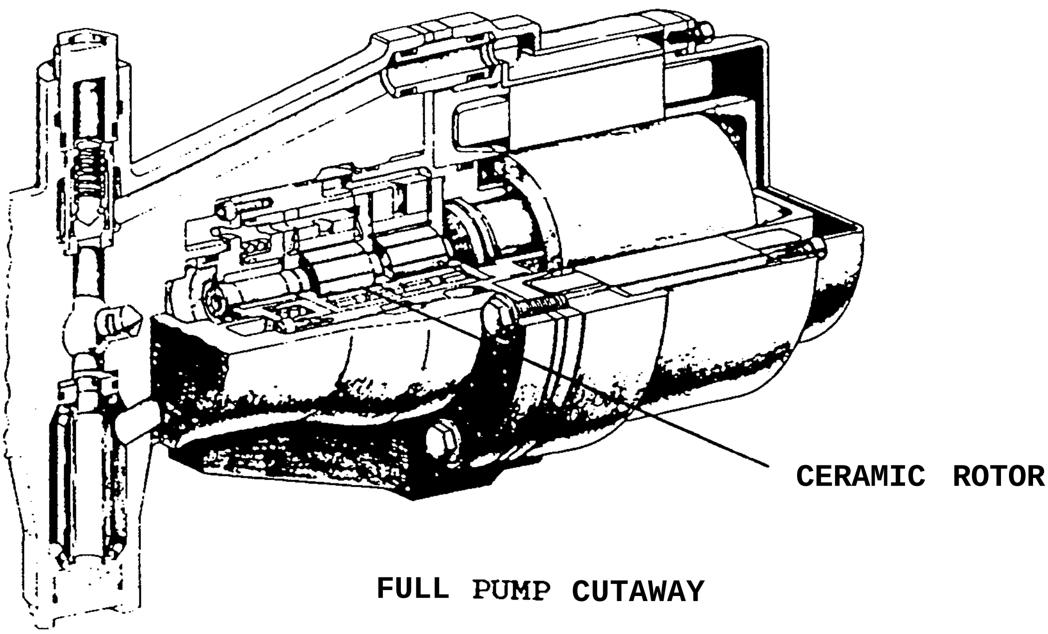
A stress analysis has been performed on a ceramic vane pump rotor to determine cyclic life. Ceramics were chosen for the rotor due to the corrosive nature of the application as well as its good wear resistance. Due to the brittle nature of the ceramics and the desire to accurately predict cyclic life, determination of the peak elastic stress was a major concern. Finite element analysis, namely MSC/NASTRAN, was initially chosen for the analysis. Due to the unacceptably high stresses found during the analysis, geometric design iterations were required to reduce these stresses and raise the predicted cyclic life. BEASY, a boundary element analysis method, was ultimately chosen for this task due to the simplified nature of geometric input and meshing.

ANALYSIS PROCEDURE

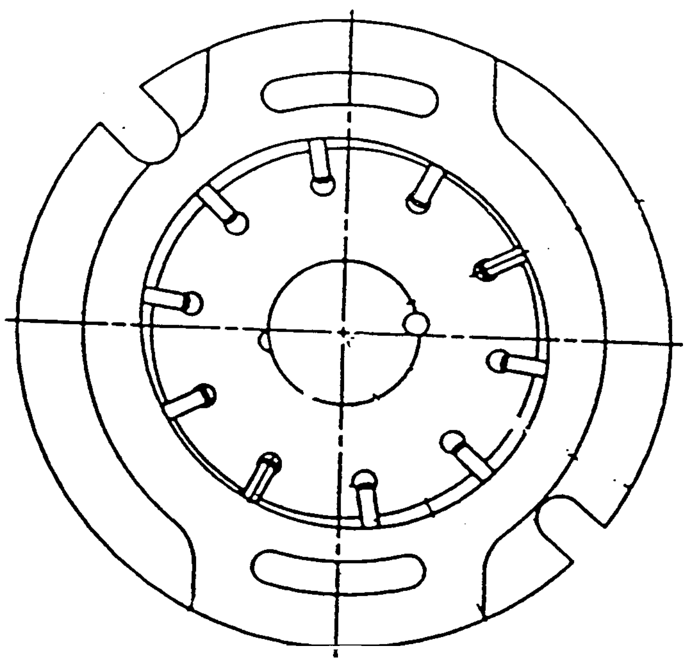
The ceramic vane rotor is shown in Figure 1 inside the cam block with its vanes. During one half of a revolution of the rotor a single vane slot is subject to seven distinct loading conditions. Two of these loading conditions ,shown in Figure 2, combine to produce the maximum to minimum stress range in the slot fillet. Rotational inertia loads were found to be insignificant and were not included in the analysis. A MSC/NASTRAN model of the original geometry was created and is shown in Figure 3. The model assumes a plain strain approach and uses 4 noded and 8 noded plate elements. The entire rotor was modeled to remove the point of boundary condition application away from the area of stress recovery. It can be seen from Figure 3 that the concentration of elements and area of interest was around only one slot fillet. Based on the two extreme loading conditions, this model predicted unacceptably high stresses in the base of the slot fillet. In order to reduce the subsequent stress range to an acceptable level, several design parameters were taken into consideration.

The first and most obvious geometric dimensions for consideration are those for the fillet at the base of the vane slot(see Figure 2). The overall outer diameter of the rotor as well as the shaft diameter were fixed and could not be increased or decreased without significant design impact. Lastly the number of vanes and the width of the vane slots could not be modified. A summary of dimensional parameters is shown in Figure 4.

Although it seems an increase in the slot fillet radius would cause a drop in fillet stress through a reduction in stress concentration, by increasing this dimension the amount of material between slots (W_{BS}) begins to decrease. In addition, the thickness of the continuous ring material below the slot(T_{CR}) also decreases. These two factors tend to increase the fillet stress by reducing the effective area available to resist the previously



FULL PUMP CUTAWAY



SECTION OF ROTOR IN CAM BLOCK

FIGURE 1

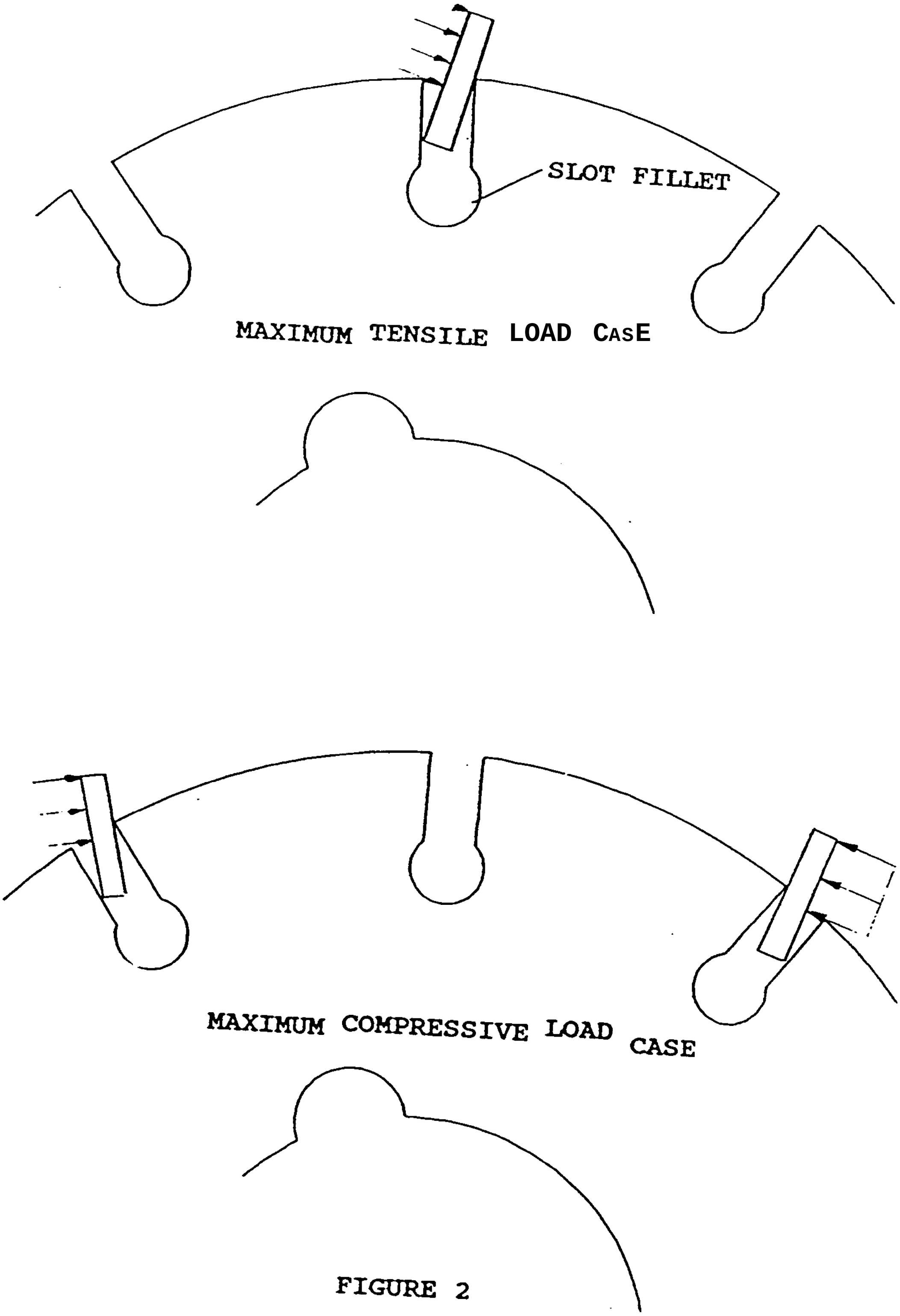
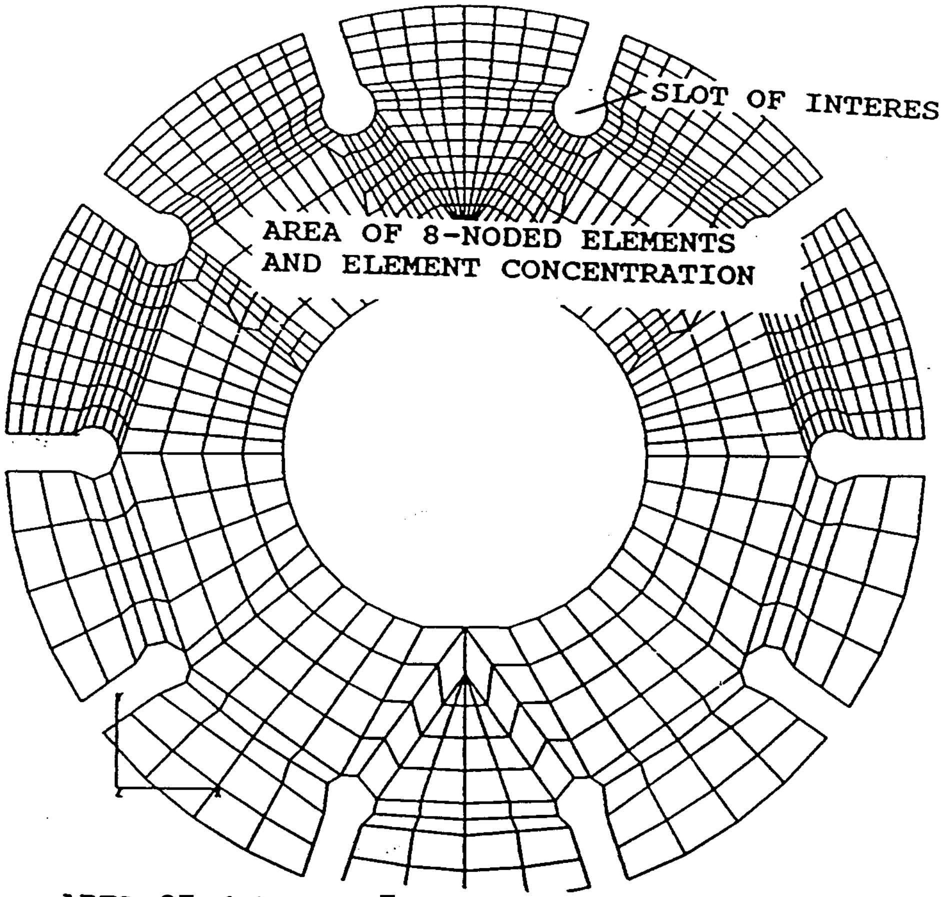

SLOT FILLET
MAXIMUM TENSILE LOAD CASE
MAXIMUM COMPRESSIVE LOAD CASE

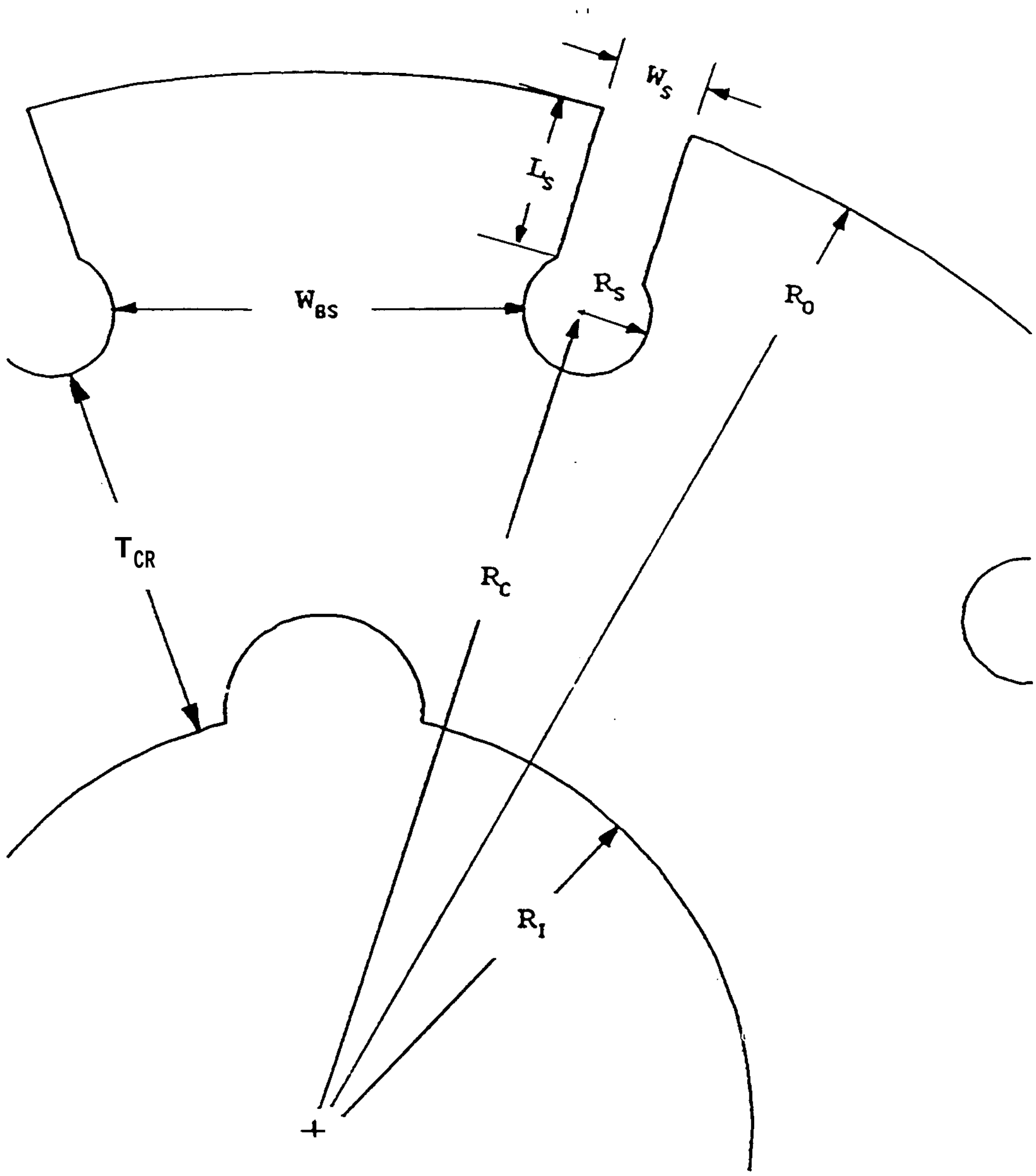
FIGURE 2



ORIGINAL NASTRAN MODEL

FIGURE 3

4
5



DIMENSION	DESCRIPTION
W_S	WIDTH OF SLOT
* L_S	LENGTH OF SLOT
* R_S	RADIUS OF SLOT FILLET
R_O	OUTER RADIUS
R_I	INNER RADIUS
W_{BS}	WIDTH BETWEEN SLOTS
T_{CR}	THICKNESS OF CONTINUOUS RING
* R_C	RADIUS TO SLOT FILLET

* parameters AVAILABLE FOR MODIFICATION

FIGURE 4

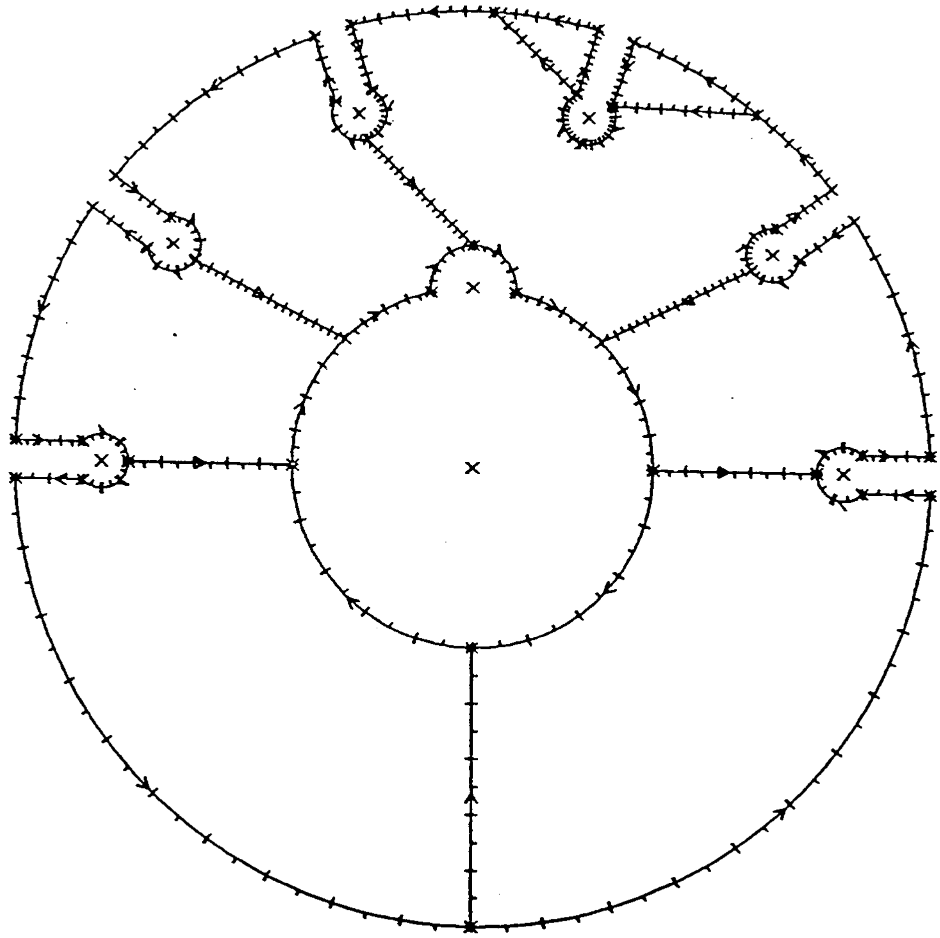
discussed vane loads.

This was proven when a second NASTRAN model was created that increased this fillet dimension. The overall mean stress as well as the cyclic stress was increased for this new geometry. The turn around time for this analysis was found to be excessively high and in addition too laborious to consider another geometry. It was decided that BEASY could provide a quicker medium for geometry iteration.

The original BEASY model was created to match the first NASTRAN model and is shown in Figure 5. When the stress results of the BEASY and NASTRAN models were compared they originally showed about a 15% difference in peak value with the BEASY values being the higher of the two(based on nodal results from the 8-noded quadratic elements). Further investigation revealed some loading inconsistencies and geometric differences that were corrected. There remained, however, a 5-10% difference in peak values in both the maximum and minimum stress for load cases 1 and 2. Due to the pressing nature of the design, the difference was temporarily accepted and the iterations were started. It was assumed that whatever the difference was it would be a consistent one and that an optimized design in BEASY would be an optimized design overall. The difference between the two codes was not ignored and while the design iterations for the pump were underway an investigation into the different stress predictions was started. A discussion of this discrepancy follows the results of the geometric iterations.

RESULTS OF GEOMETRIC ITERATIONS

A convenient form of presenting the results from the analysis is shown in Figure 6. It plots the surface stress along the inside contour of the fillet for both the maximum and minimum stress load cases. Table I shows a



ORIGINAL BEASY MODEL

FIGURE 5

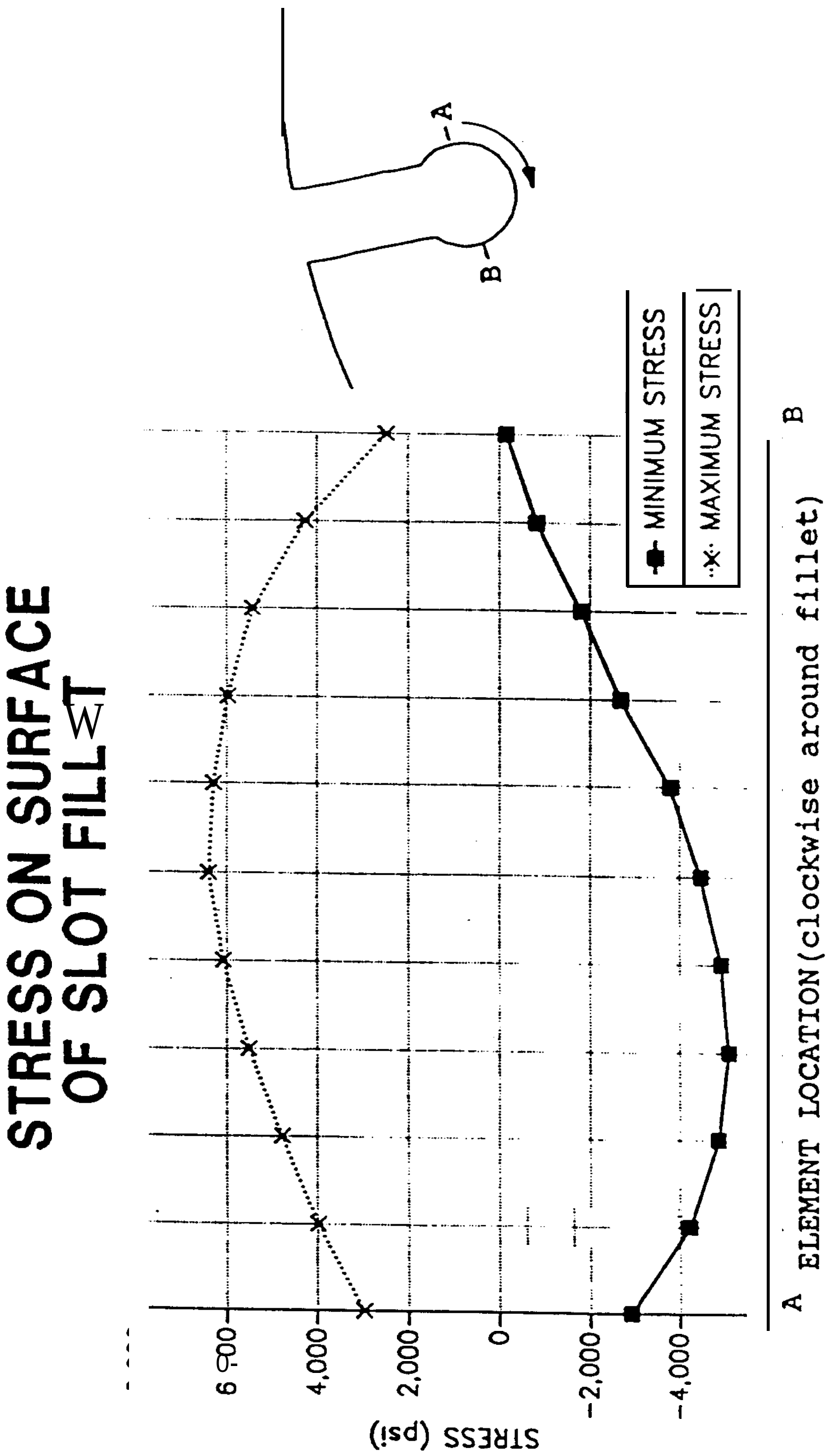

STRESS ON SURFACE
OF SLOT FILLET
STRESS (psi)
6,000
4,000
2,000
0
-2,000
-4,000
MINIMUM STRESS
MAXIMUM STRESS
A
B
ELEMENT LOCATION(clockwise around fillet)

FIGURE 6

DIMENSION	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
L_s	.075	.053	.085	.040	.054	.075
R_s	.030	.035	.035	.040	.040	.029
R_c	.413	.429	.397	.435	.432	.425
R_o	.509	.509	.509	.519	.519	.519

TABLE I

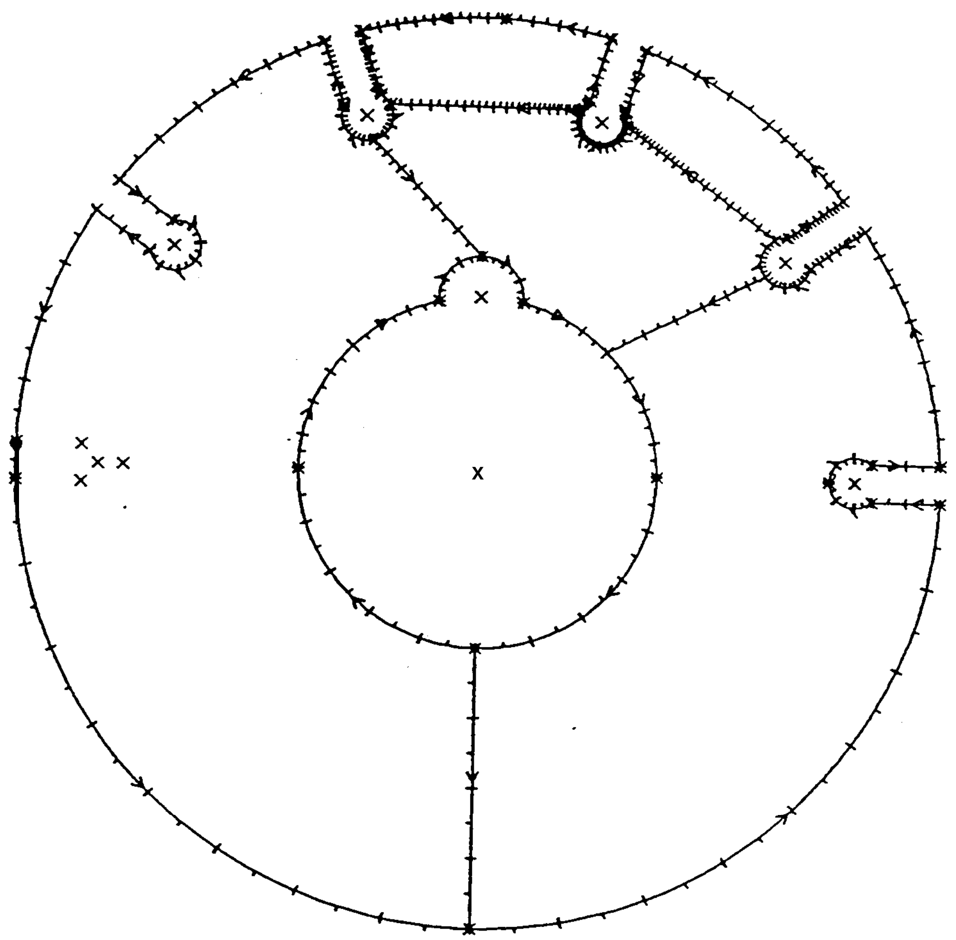


FIGURE 7

FINAL BEASY MODEL
(CASE 6)

listing of the different geometries analyzed using the BEASY method. Each successive geometry was determined by the results of the previous iteration. It was found that the amount of continuous ring material below the fillet base was a major driver in the stress reduction. In fact the concept of a "stress concentration" in the slot fillet was ultimately overridden by the need to increase this continuous ring area. This is shown in the final optimized geometry of Figure 7 in which the fillet radius is actually reduced to increase this area.

In order to perform a new geometry iteration in BEASY only a few lines of the input deck describing new geometry and loads needed to be changed. A plot summarizing all the geometries and their resulting stresses is shown in Figure 8. Overall a 17% reduction in peak alternating stress was achieved using BEASY in this iterative procedure.

RESULTS OF BEASY vs NASTRAN INVESTIGATION

After a thorough check of all boundary conditions, loads and input geometry, both analysis techniques seemed to have all things in order. The next area investigated was the mesh densities for the area of interest. It was an easy task in BEASY to plot the element stresses through the fillet and pinpoint any area of discontinuity at connecting end points. This plot is shown for the original geometry in Figure 9. Although the tune was not perfectly smooth it showed acceptable continuity in the area of peak stress. In order to perform the same manner of mesh check in NASTRAN, the nodal stresses were recovered by hand and plotted in a similar fashion. They are shown in Figure 10. It seemed that both plots showed a reasonable and smooth curve in the area of peak stress.

At this point in the analysis the geometric

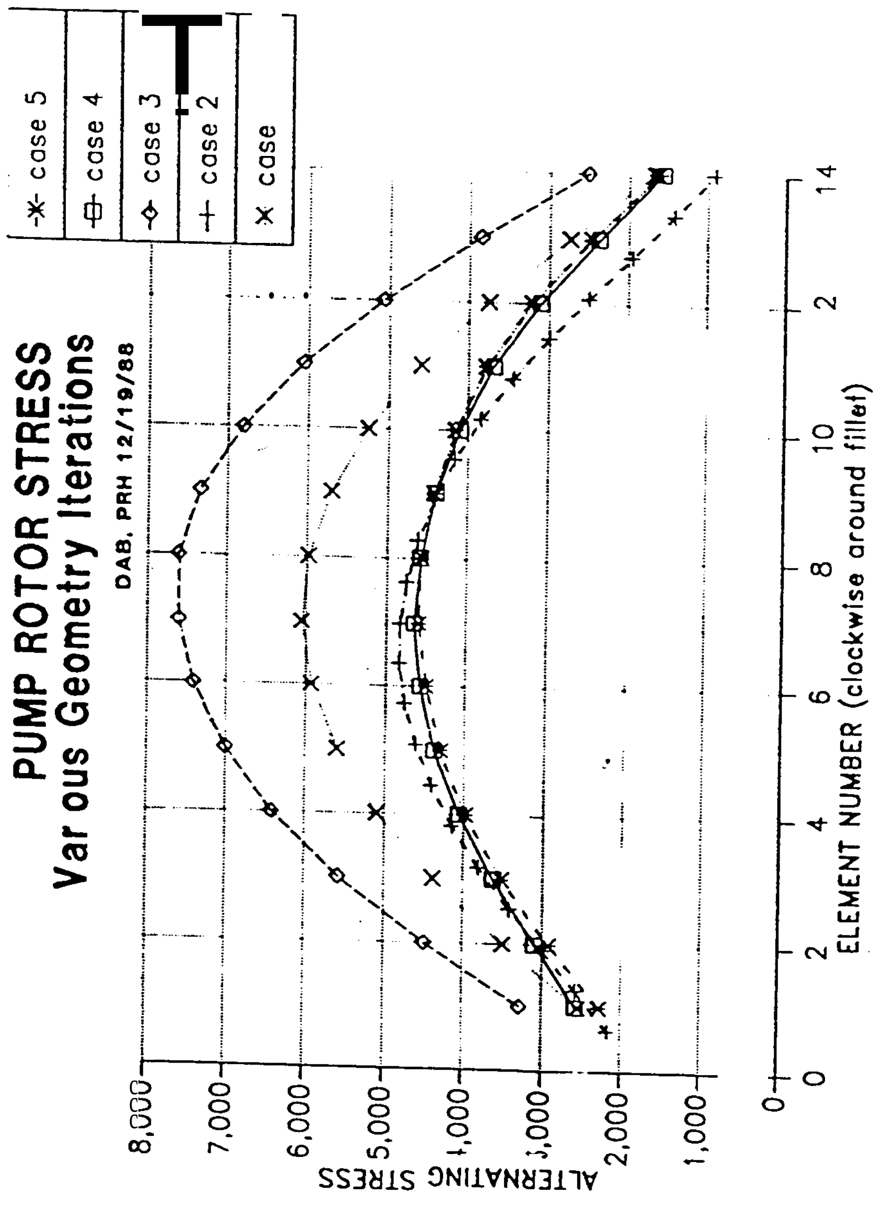

PUMP ROTOR STRESS
Var ous Geometry Iterations
DAB, PRH 12/19/88
case 5
case 4
case 3
case 2
case
ALTERNATING STRESS
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
2
4
6
8
10
12
14
ELEMENT NUMBER (clockwise around fillet)

FIGURE 8

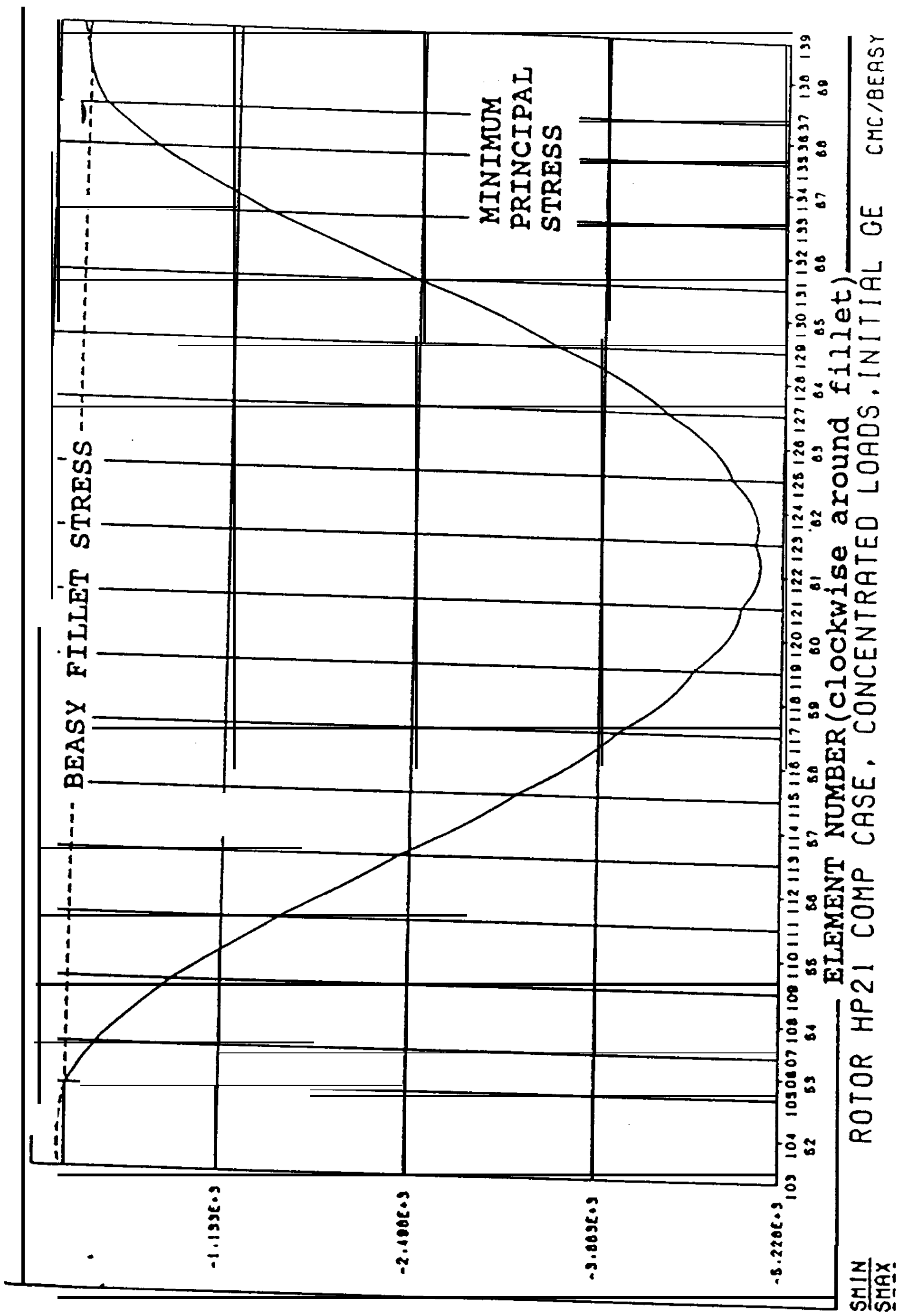

BEASY FILLET STRESS
MINIMUM PRINCIPAL STRESS
ELEMENT NUMBER(clockwise around fillet)
ROTOR HP21 COMP CASE, CONCENTRATED LOADS, INITIAL GE
CMC/BEASY
SMIN
SMAX
-1.133E+3
-2.498E+3
-3.863E+3
-5.228E+3

FIGURE 9

iterations had been completed and no solution to the differences had been found. It was decided that a final and finer mesh would be run in both BEASY and NASTRAN for the optimized geometry. The finer BEASY mesh was very similar to the old BEASY mesh with the exception of more elements in the fillet. It showed a minimal change in predicted stress. The new NASTRAN model, however is shown in Figure 10 and shows an extreme concentration of elements in the fillet area. This new mesh predicted stresses approximately 10% higher than the original mesh, and agreed well with the BEASY model.

CONCLUSION

BEASY was found to be an effective tool for both geometric iterations and accurate first cut prediction of peak elastic stresses. It subsequently proved to be invaluable in predicting a final peak elastic stress first missed when analyzed with NASTRAN. NASTRAN was able to match this peak stress but only after a deliberate and highly concentrated effort that was instigated by a mismatch with BEASY. This analysis and resulting study of meshing provided insight into the benefits of the boundary element analysis method and its relative insensitivity to mesh density.

NASTRAN RESULTS IN ROTOR

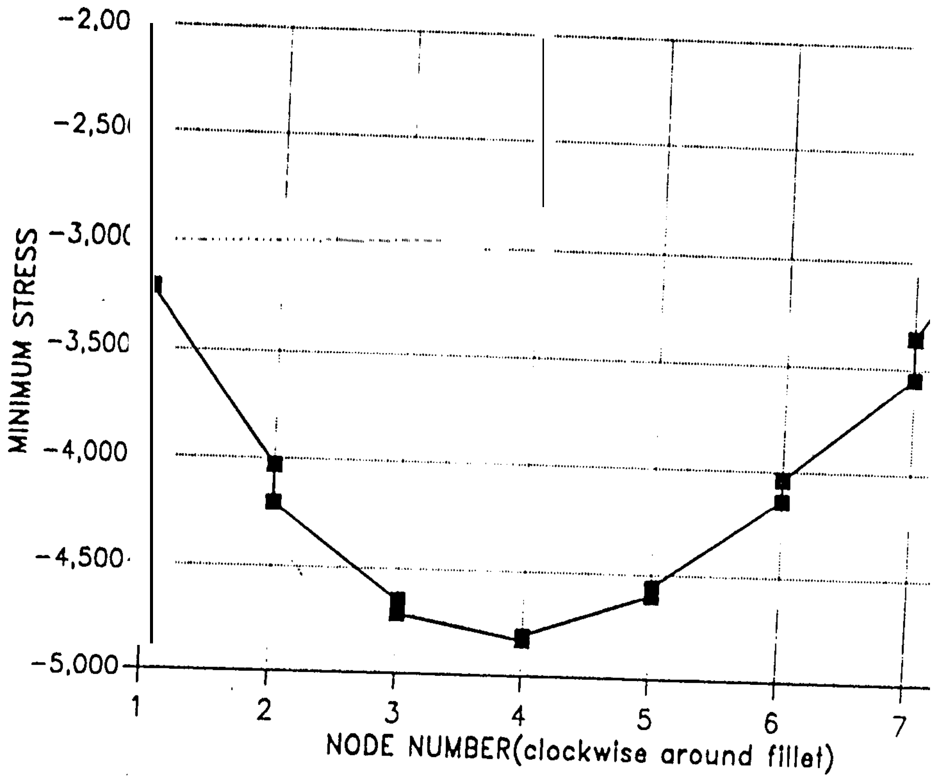
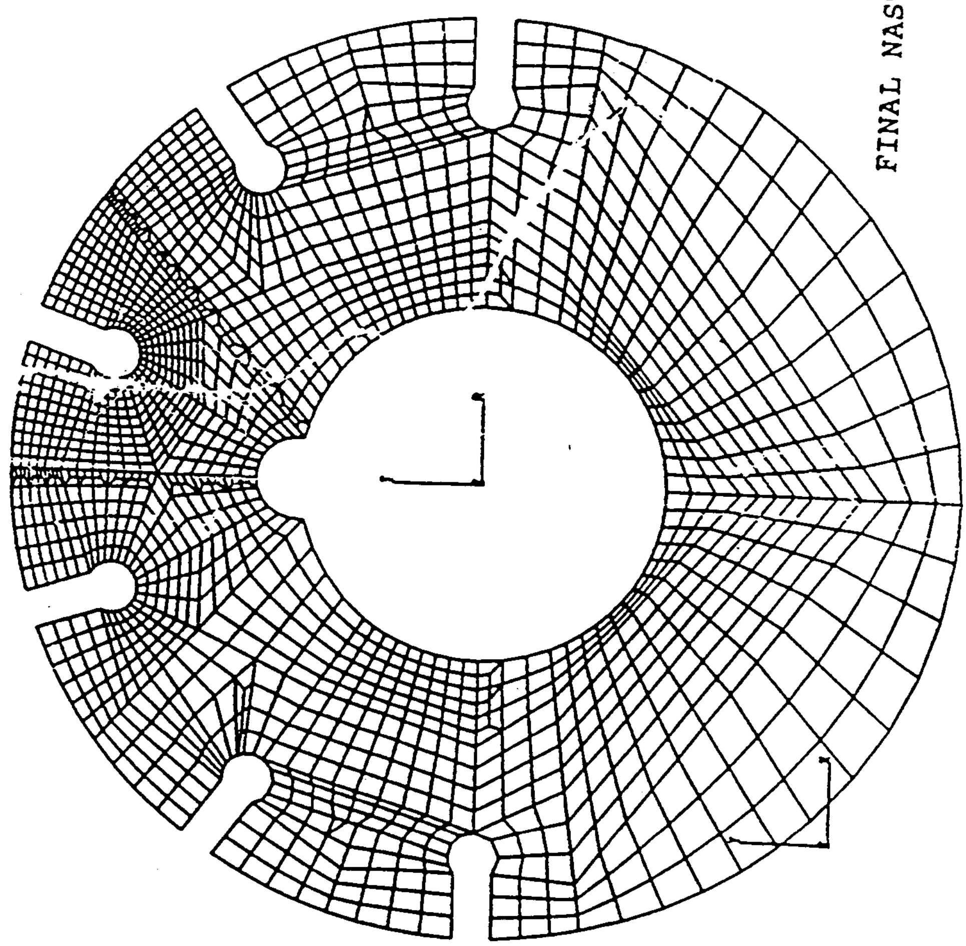


FIGURE 10



FINAL NASTRAN MESH

FIGURE 11