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1.0 INTRODUCTION

The Intermediate Size Inducer Pump (ISIP) utilizes the pump frame from the FFTF Prototype Pump as a test vehicle for an inducer impeller assembly. Construction requirements for the FFTF prototype pump may be found in Westinghouse Specification IWS-1551, which was written for the complete pump. ESG Specification N266ST310001 covers construction requirements for those parts used in the ISIP design to replace prototype pump parts. A complete description of the prototype pump is given in the Westinghouse Operation and Maintenance Manual, OMM-051-00-005. The ISIP Operation and Maintenance Manual N266OMM000001 (Reference 10) describes those parts of the pump assembly which are different for the ISIP configuration.

Structural analyses of the ISIP components in the region of the inducer/impeller assembly was performed to determine the effects of steady-state operation and of thermal transients which are defined as part of the test requirements in the ISIP specification. Evaluation of the structural integrity of the ISIP parts was based on using analytical methods and acceptance criteria of the Section III ASME Boiler and Pressure Vessel Code and appropriate RDT^{*} standards as applied to designs for high-temperature service. Evaluation of the steady-state effects are reported in N266SR000001 (Reference 5). This report covers the effects of operation during thermal transients, superimposed on those steady-state conditions.

In addition to the structural analysis, a thermal deformation analysis was conducted to determine the effects of thermal transients on critical regions such as fits and running clearances to permit evaluation of the functionability of the design and of the restrictions, if any, which should be placed on transient testing.

* RDT F9-4 (REF. 1)

2.0 SUMMARY

The thermal deformation analysis was performed for the six test transients for which thermal analysis are reported in Reference 7. The critical clearance changes between rotating and static components are listed in Table 1.

The analysis shows a reduction of 3 mils during thermal transient E-207 at the bearing and journal, and a 7-mil clearance reduction at the rear labyrinth seal during transient E-203.

Table 2 summarizes the results of component strain evaluation. Based on the criteria of RDT Standard F9-4, Section 6, for strain limit, the total accumulated strain of 0.23% is within the 1%, and the total creep-fatigue damage fraction of 0.026 is less than 0.6 as allowed in the specification (REF. 6)

3.0 DISCUSSION

The functional and structural integrity of the inducer/impeller assembly of the intermediate size inducer pump was evaluated based on Subsection NB, Section III Class 1 and Code Case 1592. In addition to the Code criteria used for evaluation of the final analysis, the following stress limits were used for evaluation of the initial steady-state analysis performed by Rocketdyne (Division 055) under IDWA N-1289 (Reference 5).

Steady-state stress limits for Type 304SS and CF8 stainless steel parts at 1050°F were:

$$\left. \begin{array}{l} \text{Primary Membrane Stress } (P_m) = 7,450 \text{ psi} \\ \text{Local Membrane Plus Bending } (P_L + P_b) = 7,730 \text{ psi} \end{array} \right\} \text{Ref. 8}$$

The design criteria for the A286 material used in the shaft extension tie-bolt at 1050°F are:

$$\left. \begin{array}{l} P_m = 15,000 \text{ psi} \\ P_L + P_b = 20,000 \text{ psi} \end{array} \right\} \text{Ref. 8}$$

These steady-state stress limits were selected to have adequate margin below the Code criteria, to provide a high probability of success in meeting the Code criteria during subsequent transient analyses.

Before using the ESG thermal model for analysis of ISIP test transients, an "umbrella" set of transients was selected from those actual transients which had been run during sodium testing of the FFTF prototype pump and analyzed with the ESG thermal model. Reference 4 shows a comparison of the calculated temperatures output from the ESG model

(using actual test input data) to actual temperatures measured during the tests. This data was used to verify the validity of the model. The model was then used with the ISIP test input requirements (which do not differ from previous FFTF pump test requirements) to show that the predicted temperature variations around the critical sodium bearing support structure and other adjacent FFTF parts would not be more severe, or significantly different, than those which had been previously undergone during sodium tests. Structural integrity of the prototype pump parts and functionability of the sodium bearing during ISIP transient tests was based on these results. For the recently designed ISIP parts, results of the thermal analysis were used as input to the ESG stress model for structural evaluation. Calculated stresses for the thermal transient stresses are shown in Table 2.

3.1 TEST CRITERIA

The original transient test requirements of the ISIP specification (Reference 6) included nine thermal transients identical to those previously specified for the FFTF prototype pump. Three of the transient tests were subsequently deleted, leaving six transient tests to be performed on the ISIP, as presently described in Reference 9. The three transients which were deleted were judged not to be significant to the ISIP parts and would only retest the overall pump structure. Based on the test request, the total operating time is expected to be approximately 4000 hours. It is estimated that about 3000 hours will be logged as steady-state operation at 950°F, including a 2000-hour design point endurance run and a 300-hour off-design endurance run, and the remainder of the time will be at reduced temperatures (400°F to 850°F). The total time during which the pump structure will be responding to thermal transients will be less than 6 hours.

Table B-37 shows the six thermal transients from the present test request. The original maximum temperature, as listed in the design specification, was 1050°F. For testing, this temperature was later reduced to 950°F as being more representative of the maximum temperature for which present LMFBR's are being designed.⁽⁹⁾ The rate and range (Δt) of the transients was not changed.

3.2 ANALYTICAL PROCEDURE

The analysis of deformation and stress of the inducer/impeller assembly was performed using the APSA (Axisymmetrical, Planar Structural Analysis) finite element computer code. Finite element models were developed to structurally represent the area of concern. A separate finite element model consisting of time histories of temperature field for thermal transients was developed. The TAP (Thermal Analysis Program) computer code was used to calculate and provide the temperature field. The worst critical time slice in determining the maximum stress and maximum deformation at various sections of the pump was determined from TAP printout. APSA computer model utilized the TAP temperature field for thermal stress analysis and the deformation analysis.

The steady-state condition (operating condition) which considered the maximum combination of stresses was documented in Reference 5. The stress intensities of various sections were utilized in the calculation of strain fatigue evaluation.

3.3 TRANSIENT DATA

Temperature distributions in the pump inducer/impeller regions were determined as a function of time for the transients.

Transients, time-history thermal analysis was performed and documented in Reference 7. The calculated temperature results were stored on tapes that were used as input for the deformation and stress analysis. The points for which temperatures were calculated and stored are exhibited in Figure 3.

The capacitance-weighted average temperature of various locations in the inducer/impeller region were determined as a function of time and transient. The differences between these temperatures were plotted, as exhibited in Appendix B.

The capacitance-weighted average temperature plots were examined to determine the worst time slice for various interfaces. There were six transients considered (Reference 7), and two worst time slices for each transient were utilized in determining the deflection and stress. The clearance change at various interfaces utilized the transient time slice and were documented in Appendix B. Table 3 shows the worst stress intensities of the pump element for each transient.

3.4 STRUCTURAL CRITERIA

The structural criteria employed in evaluating the pump inducer/impeller is described below.

All components were evaluated using elastic analysis methods as provided for in the pump specification (Reference 6, Paragraph 3.2.4). The analysis criteria are as presented in the RDT Standard F9-4(REF. 1) "Construction of Nuclear System Components at Elevated Temperature."

A summary of the method used in evaluating the strain fatigue limits is outlined below:

Structural Analysis Method Outline

Accumulated Strain Analysis (Ref.1)

Bree Complete Relaxation Method. Deformation and strain limits for structural integrity are considered to have been satisfied and a detailed inelastic ratcheting analysis need not be performed if the following four conditions are satisfied:

1. The approximate inelastic strain averaged through the thickness, ϵ_{avg} , is less than the limit of T-1310 of RDT F 9-4, with:

$$\epsilon_{avg} = \epsilon_c + \epsilon_r ,$$

where: ϵ_c = cumulative creep strain based on the primary stress $(P_L + P_b/K_t)^*$ and the appropriate isochronous stress-strain curves,

ϵ_r = cumulative ratchet strain based on Bree's complete relaxation analysis.

The values of ϵ_r are given by:

$$\epsilon_r = \sum_i N_i (\Delta\epsilon_r)_i ,$$

where: N_i = number of type i cycles,

$(\Delta\epsilon_r)_i$ = ratchet strain per cycle for type i cycles from Bree's complete relaxation equations.

$$(\Delta \epsilon_r)_i = \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\} ,$$

in region S_1 of Fig. 4

$$(\Delta \epsilon_r)_i = \frac{S_m}{E} \left\{ 1 - x'' + 2y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\} ,$$

in region R_1 of Fig. 4

$$(\Delta \epsilon_r)_i = \frac{S_m}{E} [x''(y'' - 1)] ,$$

in regions S_2 and P of Fig. 4 and:

$$(\Delta \epsilon_r)_i = \frac{S_m}{E} [x''(2y'' - 1) - 1] ,$$

in region R_2 of Fig. 4 In the above:

$$x'' = \left(P_L + \frac{P_b}{K_t} \right) / S_m$$

and:

$$y'' = (Q_R)_{\max} / S_m ,$$

Creep-Fatigue Damage Analysis (SIMPLIFIED METHOD)

Assume $\epsilon_{eff} = \epsilon_{eff \text{ range}} = \epsilon_t$

Assume $\epsilon_{eff} = \frac{\sigma_{eff}}{E}$

- 1) Pick σ_{eff} and E for the relevant element in the APSA printout (namely, the element at the critical surface of the selected section), for every transient.
- 2) Using the "Design ϵ_t vs No. of Allowable Cycles" plot, Figure T1430 (CODE CASE 1592) , find N_d for every transient.
- 3) Determine the number of occurrences for each transient
- 4) Total fatigue damage fraction = $\sum \frac{n}{N_d}$.
- 5) Creep Damage Analysis: Creep Damage Fraction - Simplified Analysis Method for the Cycle Selection

Determine $[P_L + P_B + Q_{\max}]$

If $S_y \geq [P_L + P_B + Q_{\max}]$ then $S_K = [P_L + P_B + Q_{\max}]$

If $S_y \leq [P_L + P_B + Q_{\max}]$ then

$$S_K = \frac{\text{lesser of } 1.25 \times S_y}{\cdot}$$

In stress rupture curve, find T_d using $\frac{S_K}{0.9}$.

$$6) \sum \frac{n}{N_d} + \sum \frac{t}{T_d} \leq 0.6$$

FIG 1 SCHEMATIC OF INDUCER-IMPELLER ASS'Y

TABLE 1
CRITICAL CLEARANCE CHANGES
(mils)

Location*	Design Clearance	Transient					
		E-202 100 sec	E-203 100 sec	E-204 100 sec	E-207 275 sec	E-208 115 sec	E-210 50 sec
A	13	+2.4	-1.7	+3.1	+4.6	+3.7	+2.2
B	13	+1.9	-1.3	+2.6	+3.5	+2.8	+2.4
C	50	+6.7	-7.2	+9.2	+11.8	+10.6	+6.6
D	50	+0.9	+5.2	-0.7	-1.5	-0.9	+2.6
E	50	+2.0	+2.9	-3.3	-2.9	-3.7	-3.0
F	50	+8.7	-6.1	+11.6	+13.0	+13.1	+10.5

Note: The values listed under the transient column are changes in the original clearance at isothermal temperature conditions.

For example, at Location A, the original clearance (13 mils) is increased by 0.0024 in. during Event E-202 and decreased by 0.0017 in. during E-203.

*See Figures 1 and 2.

ROTATING ASSEMBLY

STATIC ASSEMBLY

FIG. 2 FINITE ELEMENT MODEL

FIG. 3 TYPICAL TEMPERATURE FIELD

Fig. 4 Ratchet Limits

COMPONENT (ELEMENT)	TEST TRANSIENT						STRAIN SOURCE	Design Margin
	E-202	E-203	E-204	E-207	E-208	E-210		
	%	%	%	%	%	%		
INDUCER HUB (531)	0.00073	0.00056	0.00380	0.00110	0.00450	0.00380	Q Per cycle	$D.M. = \frac{1\%}{.034} - 1$ >10
	0.02	0.02	0.02	0.02	0.02	0.02	P _m	
	ACCUMULATED STRAIN						0.034 %	
INDUCER BLADE (666)	0.00108	0.01042	0.01903	0.01100	0.02100	0.01790	Q	7.33
	0.04	0.04	0.04	0.04	0.04	0.04	P _m	
	ACCUMULATED STRAIN						0.12 %	
IMPELLER (648)	0.00977	0.00200	0.00990	0.00840	0.01230	0.00980	Q	9.86
	0.04	0.04	0.04	0.04	0.04	0.04	P _m	
	ACCUMULATED STRAIN						0.092 %	
SHAFT (412)	0.01020	0.00960	0.02100	0.04540	0.02800	0.01100	Q	3.44
	0.1	0.1	0.1	0.1	0.1	0.1	P _m	
	ACCUMULATED STRAIN						0.225 %	

TABLE 2 COMPONENT STRAIN (Allowable strain 1%)

PREPARED BY:

CHECKED BY:

DATE:

Rockwell International
Energy Systems GroupN266SR000002
21

REPORT NO.

MODEL NO.

COMPONENT (ELEMENT)	TEST TRANSIENT					
	E-202	E-203	E-204	E-207	E-208	E-210
	100 hrc	100 hrc	100 hrc	275 hrc	115 hrc	50 hrc
INDUCER HUB (531)	15400	15800	20000	16000	20600	19000
INDUCER BLADE (666)	13000	22200	27600	22200	28000	25600
IMPELLER (648)	21200	14000	21000	19800	22000	20000
SHAFT (412)	18800	18600	25000	33400	28160	18400

TABLE 3 THERMAL STRESS (Q) psi

PREPARED BY:

CHECKED BY:

DATE:

Rockwell International
Energy Systems GroupN266SR000002
22

MODEL NO.

4.0 REFERENCES

1. Guidelines and Procedures for Design of Nuclear System Components at Elevated Temperature, RDT F 9-4
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5. M. Sasaki, "Steady-State Structural Analysis (Pump Internal)," N266SR00001, Rocketdyne Division, Rockwell International (August 7, 1978)
6. Design Specification, "Pump Sodium, Inducer Intermediate (ISIP) (Impeller/Inducer/Diffuser Retrofit)," N266ST310001
7. E. M. Mouradian, A. A. Loffredo, and K. H. Yun, "Transient Thermal Analysis of ISIP (Intermediate-Size Inducer Pump)," N266TI000-008, Atomics International, Rockwell International (April 30, 1979)
8. T. J. Boardman, "Intermediate-Size Inducer Pump Technical Requirements," N266TI000001, Atomics International, Rockwell International (January 20, 1978)
9. J. O. Pfouts, "Sodium Testing of Intermediate-Size Inducer Pump in SPTF at ETEC," N266RFT000001, Atomics International, Rockwell International (April 24, 1979, Revision C)

10. Operating and Maintenance Manual Addendum to Westinghouse OMM-051-00-005 for Intermediate-Size Inducer Pump, Model 266, N2660MM000001, Atomics International, Rockwell International (November 20, 1978)

APPENDIX A
STRUCTURAL ANALYSIS

- a. Strain Limit Evaluation
- b. Creep-Fatigue Damage Evaluation

STRUCTURAL ANALYSIS

The Bree Complete Relaxation Method of RDT Standard (Reference 1) was used to determine the creep strain limit for pump components. The primary stress ($P_b + P_1$) has utilized the stress intensity value from the stress report by Rocketdyne on the steady-state stress analysis (N266SR000001, Reference 5). The thermal transients stress (Q) were obtained from the time-history iteration of transients. Two worst-time slices were selected for each transient. The procedure was described in Section 3 of this report.

Table A-1 and Table A-2 summarized the stresses and strains, respectively, for different parts of inducer-impeller assembly for each transient.

The total creep-fatigue damage fraction was analyzed based on the method described in Section 3 of this report. The calculation showed that the creep-fatigue damage fraction of 0.026 which was smaller than 0.6.

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stress Intensities (steady state)

Component	Stress	D.M.
@ Inducer hub	$P_m = 2.93 \text{ Ksi}$	1.63
@ Inducer Blade	$P_m = 5.6 \text{ Ksi}$	0.38
@ Impeller	$P_m = 5.9 \text{ Ksi}$	0.31
@ shaft	$P_m = 7.48 \text{ Ksi}$	0.03

* stress intensity are from N266SR000001 (ref. 5)

- 1) See page 8
- 2) stress intensities base on 1050°F
- 3) Actual $T = 950^\circ\text{F}$
- 4) $S_o = 14,300 \text{ psi}$ (used $7,730 \text{ psi}$ in this Analysis)

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Strain Limits Evaluation

@ Inducer Hub

$$P_b + P_L / 0.9 = 2.9 \text{ KSI}$$

$$\epsilon_c = 0.02 \%$$

(Fig. T-1800-A.4
Code Case 1592)

@ Inducer Blade

$$P_b + P_L / 0.9 = 5.6 \text{ KSI}$$

$$\epsilon_c = 0.04 \%$$

@ Impeller

$$P_b + P_L / 0.9 = 5.9 \text{ KSI}$$

$$\epsilon_c = 0.04 \%$$

@ shaft

$$P_b + P_L / 0.9 = 7.5 \text{ KSI}$$

$$\epsilon_c = 0.1 \%$$

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COMPONENT (ELEMENT)	TEST TRANSIENT						STRESS SOURCE (Ksi)
	E-202	E-203	E-204	E-207	E-208	E-210	
	100 <i>hec</i>	100 <i>hec</i>	100 <i>hec</i>	275 <i>hec</i>	115 <i>hec</i>	50 <i>hec</i>	
INDUCER HUB (531)	2.93	2.93	2.93 <i>Ksi</i>	2.93	2.93	2.93	P _m
	15.4	15.8	20.0	16.0	20.6	19.0	Q
	18.33	18.73	22.93	18.93	23.53	21.93	P _m + Q
INDUCER BLADE (666)	5.6	5.6	5.6	5.6	5.6	5.6	P _m
	13.0	22.2	27.6	22.2	28.0	25.6	Q
	18.6	27.8	33.2	27.8	33.6	31.2	P _m + Q
IMPELLER (648)	5.9	5.9	5.9	5.9	5.9	5.9	P _m
	21.2	14.0	21.0	19.8	22.0	20.0	Q
	27.1	19.9	26.9	25.7	27.9	25.9	P _m + Q
SHAFT (412)	7.5	7.5	7.5	7.5	7.5	7.5	P _m
	18.8	18.6	25.0	33.4	28.2	18.4	Q
	26.3	26.1	32.5	40.9	35.7	25.9	P _m + Q

TABLE A-1

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 N266SR000002

COMPONENT (ELEMENT)	TEST TRANSIENT						STRAIN SOURCE
	E-202	E-203	E-204	E-207	E-208	E-210	
	%	%	%	%	%	%	
INDUCER HUB (531)	0.00073	0.00092	0.00380	0.00110	0.00450	0.00380	Q (per cycle)
	0.02000	0.02000	0.02000	0.02000	0.02000	0.02000	P _{rm}
	0.02073	0.02092	0.02380	0.02110	0.02450	0.02380	Total
INDUCER BLADE (666)	0.00108	0.01042	0.01903	0.01100	0.02100	0.01790	Q (per cycle)
	0.04000	0.04000	0.04000	0.04000	0.04000	0.04000	P _{rm}
	0.04108	0.05042	0.05903	0.05100	0.06100	0.05790	Total
IMPELLER (648)	0.00977	0.00200	0.00990	0.00840	0.01230	0.00980	Q (per cycle)
	0.04000	0.04000	0.04000	0.04000	0.04000	0.04000	P _{rm}
	0.04977	0.04200	0.04990	0.04840	0.05230	0.04980	Total
SHAFT (412)	0.01020	0.00960	0.02100	0.04540	0.02800	0.01100	Q (per cycle)
	0.10000	0.10000	0.10000	0.10000	0.10000	0.10000	P _{rm}
	0.11020	0.10960	0.12100	0.14540	0.12800	0.11100	Total

TABLE A-2

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Strain Limits Evaluation

Test Transient E-202 @ 100 Sec.

Element 531 @ Inducer Hub (Fig. B-6)

$$Q = 15.4 \text{ Ksi}$$

$$P_m = 2.9 \text{ Ksi}$$

Temperature for E-202 $750^\circ\text{F} \rightarrow 600^\circ\text{F}$

$$\begin{aligned} S_y &= 17.3 \text{ Ksi @ } 750^\circ\text{F} \\ S_y &= 18.2 \text{ Ksi @ } 600^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 17.3 \text{ Ksi @ } 750^\circ\text{F} \\ S_y &= 18.2 \text{ Ksi @ } 600^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 17.8 \text{ Ksi}$$

$$S_m = 15.1 \text{ Ksi @ } 675^\circ\text{F (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 25.0 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\begin{aligned} x'' &= 2.9 / 15.1 = 0.19 \\ Y'' &= 15.4 / 15.1 = 1.02 \end{aligned} \quad \left. \vphantom{\begin{aligned} x'' &= 2.9 / 15.1 = 0.19 \\ Y'' &= 15.4 / 15.1 = 1.02 \end{aligned}} \right\} \text{Region } S_1$$

$$\begin{aligned} \Delta \epsilon_r &= \frac{S_m}{E} \left\{ 1 - x'' + Y'' \left[1 - 2 \left(\frac{1 - x''}{Y''} \right)^{1/2} \right] \right\} \\ &= \frac{15100}{25 \times 10^6} \left\{ 1 - 0.19 + 1.02 \left[1 - 2 \left(\frac{1 - 0.19}{1.02} \right)^{1/2} \right] \right\} \\ &= 0.00073 \% \text{ per cycle} \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-202 @ 100 Sec.

Element 666 @ Inducer Blade (Fig. B-10)

$$Q = 13.0 \text{ Ksi}$$

$$P_m = 5.6 \text{ Ksi}$$

Temperature for E-202 $750^\circ\text{F} \rightarrow 600^\circ\text{F}$

$$\begin{aligned} S_y &= 17.3 \text{ Ksi @ } 750^\circ\text{F} \\ S_y &= 18.2 \text{ Ksi @ } 600^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 17.3 \text{ Ksi @ } 750^\circ\text{F} \\ S_y &= 18.2 \text{ Ksi @ } 600^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 17.8 \text{ Ksi}$$

$$S_m = 15.1 \text{ Ksi @ } 675^\circ\text{F (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 25.0 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\left. \begin{aligned} x'' &= 5.6 / 15.1 = 0.37 \\ y'' &= 13.0 / 15.1 = 0.86 \end{aligned} \right\} \text{Region 5,}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\} \\ &= \frac{15100}{25 \times 10^6} \left\{ 1 - 0.37 + 0.86 \left[1 - 2 \left(\frac{1 - 0.37}{0.86} \right)^{1/2} \right] \right\} \\ &= 0.00108 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-202 @ 100 sec.

Element 648 @ Impaler (Fig. B-10)

$$Q = 21.2 \text{ Ksi}$$

$$P_m = 5.9 \text{ Ksi}$$

Temperature for E-202 $750^\circ\text{F} \rightarrow 600^\circ\text{F}$

$$\begin{aligned} S_y &= 17.3 \text{ Ksi @ } 750^\circ\text{F} \\ S_y &= 18.2 \text{ Ksi @ } 600^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 17.3 \text{ Ksi @ } 750^\circ\text{F} \\ S_y &= 18.2 \text{ Ksi @ } 600^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 17.8 \text{ Ksi}$$

$$S_m = 15.1 \text{ Ksi @ } 675^\circ\text{F} \text{ (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 25.0 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method (RDT F 9-5T)

$$\begin{aligned} x'' &= 5.9 / 15.1 = 0.39 \\ Y'' &= 21.2 / 15.1 = 1.4 \end{aligned} \quad \left. \vphantom{\begin{aligned} x'' &= 5.9 / 15.1 = 0.39 \\ Y'' &= 21.2 / 15.1 = 1.4 \end{aligned}} \right\} \text{Region 51}$$

Ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + Y'' \left[1 - 2 \left(\frac{1 - x''}{Y''} \right)^{1/2} \right] \right\} \\ &= \frac{15100}{25 \times 10^6} \left\{ 1 - 0.39 + 1.4 \left[1 - 2 \left(\frac{1 - 0.39}{1.4} \right)^{1/2} \right] \right\} \\ &= 0.00977 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-202 @ 100 sec.

Element 412 @ shaft (Fig. B-6)

$$Q = 18.8 \text{ Ksi}$$

$$P_m = 7.5 \text{ Ksi}$$

Temperature for E-202 $750^\circ\text{F} \rightarrow 600^\circ\text{F}$

$$\begin{aligned} S_y &= 17.3 \text{ Ksi @ } 750^\circ\text{F} \\ S_y &= 18.2 \text{ Ksi @ } 600^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 17.3 \text{ Ksi @ } 750^\circ\text{F} \\ S_y &= 18.2 \text{ Ksi @ } 600^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 17.8 \text{ Ksi}$$

$$S_m = 15.1 \text{ Ksi @ } 675^\circ\text{F (mean temp.)}$$

(Table I-14.3A code case 1592)

$$E = 25.0 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\begin{aligned} x'' &= 7.5 / 15.1 = 0.5 \\ y'' &= 18.8 / 15.1 = 1.25 \end{aligned} \quad \left. \vphantom{\begin{aligned} x'' &= 7.5 / 15.1 = 0.5 \\ y'' &= 18.8 / 15.1 = 1.25 \end{aligned}} \right\} \text{Region } S_1$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\} \\ &= \frac{15100}{25 \times 10^6} \left\{ 1 - 0.5 + 1.25 \left[1 - 2 \left(\frac{1 - 0.5}{1.25} \right)^{1/2} \right] \right\} \\ &= 0.0102 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-203 @ 100 sec

Element 531 @ Inducer Hub

$$Q = 15.8 \text{ Ksi}$$

$$P_m = 2.9 \text{ Ksi}$$

Temperature for E-203 $500^\circ\text{F} \rightarrow 650^\circ\text{F}$

$$S_y = 19.4 \text{ Ksi @ } 500^\circ\text{F}$$

$$S_y = 18.0 \text{ Ksi @ } 650^\circ\text{F}$$

$$\left. \begin{array}{l} S_y = 19.4 \text{ Ksi @ } 500^\circ\text{F} \\ S_y = 18.0 \text{ Ksi @ } 650^\circ\text{F} \end{array} \right\} S_{y_{\text{mean}}} = 18.7 \text{ Ksi}$$

$$S_m = 15.1 \text{ Ksi @ } 575^\circ\text{F (Mean Temp)}$$

(Table I-14.3A Code Case 1592)

$$E = 25.4 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$x'' = 2.9/15.1 = 0.19$$

$$y'' = 15.8/15.1 = 1.05$$

$$\left. \begin{array}{l} x'' = 2.9/15.1 = 0.19 \\ y'' = 15.8/15.1 = 1.05 \end{array} \right\} \text{Region } S_1$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$(\Delta \epsilon_r) = \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\}$$

$$= \frac{15100}{25.4 \times 10^6} \left\{ 1 - 0.19 + 1.05 \left[1 - 2 \left(\frac{1 - 0.19}{1.05} \right)^{1/2} \right] \right\}$$

$$= 0.00092 \%$$

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Strain Limits Evaluation

Test Transient E-203 @ 100 sec

Element 648 @ Impeller

$$Q = 14.0 \text{ Ksi}$$

$$P_m = 5.9 \text{ Ksi}$$

Temperature for E-203 $500^\circ\text{F} \rightarrow 650^\circ\text{F}$

$$\begin{aligned} S_y &= 19.4 \text{ Ksi @ } 500^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 650^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 19.4 \text{ Ksi @ } 500^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 650^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 18.7 \text{ Ksi}$$

$$S_m = 15.1 \text{ Ksi @ } 575^\circ\text{F (Mean Temp)}$$

(Table I-14.3A Code Case 1592)

$$E = 25.4 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\begin{aligned} x'' &= 5.9 / 15.1 = 0.39 \\ y'' &= 14.0 / 15.1 = 0.93 \end{aligned} \quad \left. \vphantom{\begin{aligned} x'' &= 5.9 / 15.1 = 0.39 \\ y'' &= 14.0 / 15.1 = 0.93 \end{aligned}} \right\} S_1 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\} \\ &= \frac{15100}{25.4 \times 10^6} \left\{ 1 - 0.39 + 0.93 \left[1 - 2 \left(\frac{1 - 0.39}{0.93} \right)^{1/2} \right] \right\} \\ &= 0.002 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-203 @ 100 sec

Element 412 @ shaft

$$Q = 18.6 \text{ Ksi}$$

$$P_m = 7.5 \text{ Ksi}$$

Temperature for E-203 500°F → 650°F

$$\begin{aligned} S_y &= 19.4 \text{ Ksi @ } 500^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 650^\circ\text{F} \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} S_{y_{\text{mean}}} = 18.7 \text{ Ksi}$$

$$S_m = 15.1 \text{ Ksi @ } 575^\circ\text{F (Mean Temp)}$$

(Table I-14.3A Code Case 1592)

$$E = 25.4 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\begin{aligned} x'' &= 7.5 / 15.1 = 0.5 \\ y'' &= 18.6 / 15.1 = 1.23 \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} S_1 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\} \\ &= \frac{15100}{25.4 \times 10^6} \left\{ 1 - 0.5 + 1.23 \left[1 - 2 \left(\frac{1 - 0.5}{1.23} \right)^{1/2} \right] \right\} \\ &= 0.0096 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-204 @ 100 sec.

Element 531 @ Inducer Hub

$$Q = 20.0 \text{ Ksi}$$

$$P_m = 2.9 \text{ Ksi}$$

Temperature for E-204 850°F → 650°F

$$\begin{array}{l} S_y = 16.5 \text{ Ksi @ } 850^\circ\text{F} \\ S_y = 17.9 \text{ Ksi @ } 650^\circ\text{F} \end{array} \quad \left. \vphantom{\begin{array}{l} S_y = 16.5 \text{ Ksi @ } 850^\circ\text{F} \\ S_y = 17.9 \text{ Ksi @ } 650^\circ\text{F} \end{array}} \right\} S_{y \text{ mean}} = 17.2 \text{ Ksi}$$

$$S_m = 15.0 \text{ Ksi @ } 750^\circ\text{F (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 24.5 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\left. \begin{array}{l} X'' = 2.9 / 15.0 = 0.19 \\ Y'' = 20.0 / 15.0 = 1.33 \end{array} \right\} S_2 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} [X''(Y''-1)] \\ &= \frac{15000}{24.5 \times 10^6} [0.19(1.33-1)] \\ &= 0.0038 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-204 @ 100 sec.

Element 666 @ Inducer Blade

$$Q = 27.6 \text{ Ksi}$$

$$P_m = 5.6 \text{ Ksi}$$

Temperature for E-204 850°F → 650°F

$$\begin{array}{l} S_y = 16.5 \text{ Ksi @ } 850^\circ\text{F} \\ S_y = 17.9 \text{ Ksi @ } 650^\circ\text{F} \end{array} \quad \left. \vphantom{\begin{array}{l} S_y = 16.5 \text{ Ksi @ } 850^\circ\text{F} \\ S_y = 17.9 \text{ Ksi @ } 650^\circ\text{F} \end{array}} \right\} S_{y \text{ mean}} = 17.2 \text{ Ksi}$$

$$S_m = 15.0 \text{ Ksi @ } 750^\circ\text{F (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 24.5 \times 10^6 \text{ psi}$$

1. Brze Relaxation Method

$$\begin{array}{l} x'' = 5.6/15.0 = 0.37 \\ y'' = 27.6/15.0 = 1.84 \end{array} \quad \left. \vphantom{\begin{array}{l} x'' = 5.6/15.0 = 0.37 \\ y'' = 27.6/15.0 = 1.84 \end{array}} \right\} S_2 \text{ Region}$$

ratchet strain per cycle

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} [x''(y''-1)] \\ &= \frac{15000}{24.5 \times 10^6} [0.37(1.84-1)] \\ &= 0.01903 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-204 @ 100 sec.

Element 64B @ Impeller

$$Q = 21.0 \text{ Ksi}$$

$$P_m = 5.9 \text{ Ksi}$$

Temperature for E-204 $850^\circ\text{F} \rightarrow 650^\circ\text{F}$

$$\begin{aligned} S_y &= 16.5 \text{ Ksi @ } 850^\circ\text{F} \\ S_y &= 17.9 \text{ Ksi @ } 650^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 16.5 \text{ Ksi @ } 850^\circ\text{F} \\ S_y &= 17.9 \text{ Ksi @ } 650^\circ\text{F} \end{aligned}} \right\} S_{y \text{ mean}} = 17.2 \text{ Ksi}$$

$$S_m = 15.0 \text{ Ksi @ } 750^\circ\text{F} \text{ (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 24.5 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\begin{aligned} X'' &= 5.9 / 15.0 = 0.39 \\ Y'' &= 21.0 / 15.0 = 1.40 \end{aligned} \quad \left. \vphantom{\begin{aligned} X'' &= 5.9 / 15.0 = 0.39 \\ Y'' &= 21.0 / 15.0 = 1.40 \end{aligned}} \right\} S_1 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - X'' + Y'' \left[1 - 2 \left(\frac{1 - X''}{Y''} \right)^{1/2} \right] \right\} \\ &= \frac{15000}{24.5 \times 10^6} \left\{ 1 - 0.39 + 1.4 \left[1 - 2 \left(\frac{1 - 0.39}{1.40} \right)^{1/2} \right] \right\} \\ &= 0.0099 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-204 @ 100 sec.

Element 412 @ shaft

$$Q = 25.0 \text{ Ksi}$$

$$P_m = 7.5 \text{ Ksi}$$

Temperature for E-204 850°F → 650°F

$$\begin{array}{l} S_y = 16.5 \text{ Ksi @ } 850^\circ\text{F} \\ S_y = 17.9 \text{ Ksi @ } 650^\circ\text{F} \end{array} \quad \left. \vphantom{\begin{array}{l} S_y = 16.5 \text{ Ksi @ } 850^\circ\text{F} \\ S_y = 17.9 \text{ Ksi @ } 650^\circ\text{F} \end{array}} \right\} S_{y \text{ mean}} = 17.2 \text{ Ksi}$$

$$S_m = 15.0 \text{ Ksi @ } 750^\circ\text{F (mean temp.)}$$

(Table I-14.3A Code Case 1542)

$$E = 24.5 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\left. \begin{array}{l} X'' = 7.5 / 15.0 = 0.5 \\ Y'' = 25.0 / 15.0 = 1.67 \end{array} \right\} S_1 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - X'' + Y'' \left[1 - 2 \left(\frac{1 - X''}{Y''} \right)^{1/2} \right] \right\} \\ &= \frac{15000}{24.5 \times 10^6} \left\{ 1 - 0.5 + 1.67 \left[1 - 2 \left(\frac{1 - 0.5}{1.67} \right)^{1/2} \right] \right\} \\ &= 0.0210 \text{ in/in} \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-207 @ 275 Sec.

Element 531 @ Inducer Hub

$$Q = 16.0 \text{ Ksi}$$

$$P_m = 2.9 \text{ Ksi}$$

Temperature for E-207 $950^\circ\text{F} \rightarrow 620^\circ\text{F}$

$$\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 620^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 620^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 17.0 \text{ Ksi}$$

$$S_m = 15.0 \text{ Ksi @ } 785^\circ\text{F (mean temp.)}$$

(Table I-14.3A code case 1592)

$$E = 24.1 \times 10^6 \text{ psi}$$

1. Brze Relaxation Method

$$\begin{aligned} x'' &= 2.9 / 15.0 = 0.19 \\ Y'' &= 16.0 / 15.0 = 1.07 \end{aligned} \quad \left. \vphantom{\begin{aligned} x'' &= 2.9 / 15.0 = 0.19 \\ Y'' &= 16.0 / 15.0 = 1.07 \end{aligned}} \right\} S_1 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + Y'' \left[1 - 2 \left(\frac{1 - x''}{Y''} \right)^{1/2} \right] \right\} \\ &= \frac{15000}{24.1 \times 10^6} \left\{ 1 - 0.19 + 1.07 \left[1 - 2 \left(\frac{1 - 0.19}{1.07} \right)^{1/2} \right] \right\} \\ &= 0.0011 \% \end{aligned}$$

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Strain Limits Evaluation

Tent Transient E-207 @ 275 sec.

Element 666 @ Inducer Blade

$$Q = 22.2 \text{ Ksi}$$

$$P_m = 5.6 \text{ Ksi}$$

Temperature for E-207 $950^\circ\text{F} \rightarrow 620^\circ\text{F}$

$$\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 620^\circ\text{F} \end{aligned} \left. \vphantom{\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 620^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 17.0 \text{ Ksi}$$

$$S_m = 15.0 \text{ Ksi @ } 785^\circ\text{F (mean temp.)}$$

(Table I-14.3A code case 1592)

$$E = 24.1 \times 10^6 \text{ psi}$$

1. Brze Relaxation Method

$$\begin{aligned} X'' &= 5.6 / 15.0 = 0.37 \\ Y'' &= 22.2 / 15.0 = 1.48 \end{aligned} \left. \vphantom{\begin{aligned} X'' &= 5.6 / 15.0 = 0.37 \\ Y'' &= 22.2 / 15.0 = 1.48 \end{aligned}} \right\} S_1 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - X'' + Y'' \left[1 - 2 \left(\frac{1 - X''}{Y''} \right)^{1/2} \right] \right\} \\ &= \frac{15000}{24.1 \times 10^6} \left\{ 1 - 0.37 + 1.48 \left[1 - 2 \left(\frac{1 - 0.37}{1.48} \right)^{1/2} \right] \right\} \\ &= 0.011 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-207 @ 275 sec.

Element 64B @ Impeller

$$Q = 19.8 \text{ Ksi}$$

$$P_m = 5.9 \text{ Ksi}$$

Temperature for E-207 $950^\circ\text{F} \rightarrow 620^\circ\text{F}$

$$\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 620^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 620^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 17.0 \text{ Ksi}$$

$$S_m = 15.0 \text{ Ksi @ } 785^\circ\text{F (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 24.1 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\begin{aligned} X'' &= 5.9/15.0 = 0.39 \\ Y'' &= 19.8/15.0 = 1.32 \end{aligned} \quad \left. \vphantom{\begin{aligned} X'' &= 5.9/15.0 = 0.39 \\ Y'' &= 19.8/15.0 = 1.32 \end{aligned}} \right\} S_1 \text{ Region}$$

Ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - X'' + Y'' \left[1 - 2 \left(\frac{1 - X''}{Y''} \right)^{1/2} \right] \right\} \\ &= \frac{15000}{24.1 \times 10^6} \left\{ 1 - 0.39 + 1.32 \left[1 - 2 \left(\frac{1 - 0.39}{1.32} \right)^{1/2} \right] \right\} \\ &= 0.0084 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-207 @ 275 sec.

Element 412 @ shaft

$$Q = 33.4 \text{ Ksi}$$

$$P_m = 7.5 \text{ Ksi}$$

Temperature for E-207 $950^\circ\text{F} \rightarrow 620^\circ\text{F}$

$$\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 620^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 18.0 \text{ Ksi @ } 620^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 17.0 \text{ Ksi}$$

$$S_m = 15.0 \text{ Ksi @ } 785^\circ\text{F (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 24.1 \times 10^6 \text{ psi}$$

1 Bree Relaxation Method

$$\left. \begin{aligned} x'' &= 1.5 / 15.0 = 0.5 \\ Y'' &= 33.4 / 15.0 = 2.23 \end{aligned} \right\} R_2 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} [x''(2Y''-1)-1] \\ &= \frac{15000}{24.1 \times 10^6} [0.5(2 \times 2.23 - 1) - 1] \\ &= 0.0454 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-20B @ 115 sec.

Element 531 @ Inducer Hub

$$Q = 20.6 \text{ Ksi}$$

$$P_m = 2.9 \text{ Ksi}$$

Temperature for E-20B $950^\circ\text{F} \rightarrow 725^\circ\text{F}$

$$\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 17.5 \text{ Ksi @ } 725^\circ\text{F} \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} S_{y \text{ mean}} = 16.7 \text{ Ksi}$$

$$S_m = 14.9 \text{ Ksi @ } 838^\circ\text{F} \text{ (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 23.7 \times 10^6 \text{ psi}$$

1. Brze Relaxation Method

$$\begin{aligned} x'' &= 2.9 / 14.9 = 0.19 \\ y'' &= 20.6 / 14.9 = 1.38 \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} S_2 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} [x''(y''-1)] \\ &= \frac{14900}{23.7 \times 10^6} [0.19 (1.38-1)] \\ &= 0.0045 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-20B @ 115 sec.

Element 666 @ Inducer Blade

$$Q = 28.0 \text{ Ksi}$$

$$P_m = 5.6 \text{ Ksi}$$

Temperature for E-20B $950^\circ\text{F} \rightarrow 725^\circ\text{F}$

$$\begin{array}{l} S_y = 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y = 17.5 \text{ Ksi @ } 725^\circ\text{F} \end{array} \quad \left. \begin{array}{l} \\ \end{array} \right\} S_{y \text{ mean}} = 16.7 \text{ Ksi}$$

$$S_m = 14.9 \text{ Ksi @ } 838^\circ\text{F} \text{ (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 23.7 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\left. \begin{array}{l} x'' = 5.6 / 14.9 = 0.38 \\ y'' = 28.0 / 14.9 = 1.88 \end{array} \right\} S_2 \text{ Region}$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} [x''(y''-1)] \\ &= \frac{14900}{23.7 \times 10^6} [0.38(1.88-1)] \\ &= 0.021\% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-20B @ 115 sec.

Element 64B @ Impeller

$$Q = 22.0 \text{ Ksi}$$

$$P_m = 5.9 \text{ Ksi}$$

Temperature for E-20B $950^\circ\text{F} \rightarrow 725^\circ\text{F}$

$$\begin{array}{l} S_y = 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y = 17.5 \text{ Ksi @ } 725^\circ\text{F} \end{array} \quad \left. \vphantom{\begin{array}{l} S_y = 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y = 17.5 \text{ Ksi @ } 725^\circ\text{F} \end{array}} \right\} S_{y_{\text{mean}}} = 16.7 \text{ Ksi}$$

$$S_m = 14.9 \text{ Ksi @ } 838^\circ\text{F} \text{ (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 23.7 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\begin{array}{l} x'' = 5.9/14.9 = 0.4 \\ y'' = 22.0/14.9 = 1.48 \end{array} \quad \left. \vphantom{\begin{array}{l} x'' = 5.9/14.9 = 0.4 \\ y'' = 22.0/14.9 = 1.48 \end{array}} \right\} \text{Region } S_1$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\} \\ &= \frac{14900}{23.7 \times 10^6} \left\{ 1 - 0.4 + 1.48 \left[1 - 2 \left(\frac{1 - 0.4}{1.48} \right)^{1/2} \right] \right\} \\ &= 0.0123 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-20B @ 115 sec.

Element 412 @ shaft

$$Q = 28.2 \text{ Ksi}$$

$$P_m = 7.5 \text{ Ksi}$$

Temperature for E-20B $950^\circ\text{F} \rightarrow 725^\circ\text{F}$

$$\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 17.5 \text{ Ksi @ } 725^\circ\text{F} \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} S_{y \text{ mean}} = 16.7 \text{ Ksi}$$

$$S_m = 14.9 \text{ Ksi @ } 838^\circ\text{F} \text{ (mean temp.)}$$

(Table I-14.3A Code Case 1592)

$$E = 23.7 \times 10^6 \text{ psi}$$

1. Bree Relaxation Method

$$\left. \begin{aligned} x'' &= 7.5 / 14.9 = 0.5 \\ y'' &= 28.2 / 14.9 = 1.89 \end{aligned} \right\} \text{Region } S_1$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\} \\ &= \frac{14900}{23.7 \times 10^6} \left\{ 1 - 0.5 + 1.89 \left[1 - 2 \left(\frac{1 - 0.5}{1.89} \right)^{1/2} \right] \right\} \\ &= 0.028 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-210 @ 50 sec

Element 531 @ Inducer Hub

$$Q = 19.0 \text{ Ksi}$$

$$P_m = 2.9 \text{ Ksi}$$

Temperature for E-210 $950^\circ\text{F} \rightarrow 800^\circ\text{F}$

$$\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 16.8 \text{ Ksi @ } 800^\circ\text{F} \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} S_{y_{\text{mean}}} = 16.3 \text{ Ksi}$$

$$S_m = 14.6 \text{ Ksi @ } 875^\circ\text{F (Mean Temp)}$$

(Table I-14.3A Code Case 1592)

$$E = 23.3 \times 10^6$$

1. Bree Relaxation Method

$$\begin{aligned} x'' &= 2.9 / 14.6 = 0.2 \\ Y'' &= 19.0 / 14.6 = 1.3 \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{Region } S_2$$

Ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} [x'' \cdot (Y'' - 1)] \\ &= \frac{14600}{23.3 \times 10^6} [0.2 (1.3 - 1)] \\ &= 0.0038 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-210 @ 50 sec
Element 666 @ Inducer Blade

$$Q = 25.6 \text{ Ksi}$$

$$P_m = 5.6 \text{ Ksi}$$

Temperature for E-210 950°F → 800°F

$$\begin{aligned}
 S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\
 S_y &= 16.8 \text{ Ksi @ } 800^\circ\text{F}
 \end{aligned}
 \left. \vphantom{\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 16.8 \text{ Ksi @ } 800^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 16.3 \text{ Ksi}$$

$$S_m = 14.6 \text{ Ksi @ } 875^\circ\text{F (Mean Temp)}$$

(Table I-14.3A Code Case 1592)

$$E = 23.3 \times 10^6$$

1. Bree Relaxation Method

$$\begin{aligned}
 x'' &= 5.6 / 14.6 = 0.38 \\
 Y'' &= 25.6 / 14.6 = 1.75
 \end{aligned}
 \left. \vphantom{\begin{aligned} x'' &= 5.6 / 14.6 = 0.38 \\ Y'' &= 25.6 / 14.6 = 1.75 \end{aligned}} \right\} \text{Region } S_2$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned}
 (\Delta \epsilon_r) &= \frac{S_m}{E} [x''(Y''-1)] \\
 &= \frac{14600}{23.3 \times 10^6} [0.38(1.75-1)] \\
 &= 0.0179 \%
 \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-210 @ 50 sec

Element 648 @ Impeller

$$Q = 20.0 \text{ Ksi}$$

$$P_m = 5.9 \text{ Ksi}$$

Temperature for E-210 $950^\circ\text{F} \rightarrow 800^\circ\text{F}$

$$\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 16.8 \text{ Ksi @ } 800^\circ\text{F} \end{aligned} \quad \left. \vphantom{\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 16.8 \text{ Ksi @ } 800^\circ\text{F} \end{aligned}} \right\} S_{y_{\text{mean}}} = 16.3 \text{ Ksi}$$

$$S_m = 14.6 \text{ Ksi @ } 875^\circ\text{F (Mean Temp)}$$

(Table I-14.3A Code Case 1592)

$$E = 23.3 \times 10^6$$

1. Bree Relaxation Method

$$\begin{aligned} x'' &= 5.9 / 14.6 = 0.4 \\ y'' &= 20.0 / 14.6 = 1.37 \end{aligned} \quad \left. \vphantom{\begin{aligned} x'' &= 5.9 / 14.6 = 0.4 \\ y'' &= 20.0 / 14.6 = 1.37 \end{aligned}} \right\} \text{Region } S_1$$

ratchet strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1-x''}{y''} \right)^{1/2} \right] \right\} \\ &= \frac{14600}{23.3 \times 10^6} \left\{ 1 - 0.4 + 1.37 \left[1 - 2 \left(\frac{1-0.4}{1.37} \right)^{1/2} \right] \right\} \\ &= 0.0098 \% \end{aligned}$$

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Strain Limits Evaluation

Test Transient E-210 @ 50 sec

Element 412 @ shaft

$$Q = 18.4 \text{ Ksi}$$

$$Q_m = 7.5 \text{ Ksi}$$

Temperature for E-210 $950^\circ\text{F} \rightarrow 800^\circ\text{F}$

$$\begin{aligned} S_y &= 15.9 \text{ Ksi @ } 950^\circ\text{F} \\ S_y &= 16.8 \text{ Ksi @ } 800^\circ\text{F} \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} S_{y_{\text{mean}}} = 16.3 \text{ Ksi}$$

$$S_m = 14.6 \text{ Ksi @ } 875^\circ\text{F (Mean Temp)}$$

(Table I-14.3A Code Case 1592)

$$E = 23.3 \times 10^6$$

1. Bree Relaxation Method

$$\left. \begin{aligned} x'' &= 7.5 / 14.6 = 0.51 \\ y'' &= 18.4 / 14.6 = 1.26 \end{aligned} \right\} \text{Region } S_1$$

Ratchet Strain per cycle ($\Delta \epsilon_r$)

$$\begin{aligned} (\Delta \epsilon_r) &= \frac{S_m}{E} \left\{ 1 - x'' + y'' \left[1 - 2 \left(\frac{1 - x''}{y''} \right)^{1/2} \right] \right\} \\ &= \frac{14600}{23.3 \times 10^6} \left\{ 1 - 0.51 + 1.26 \left[1 - 2 \left(\frac{1 - 0.51}{1.26} \right)^{1/2} \right] \right\} \\ &= 0.011 \% \end{aligned}$$

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Creep - Fatigue Damage

Test Transient

E-207

Element

$$P_m + Q = 40.9 \text{ Ksi} > S_y = 15.9 \text{ Ksi}$$

$$1.25 S_y / 0.9 = 22.0 \text{ Ksi}$$

1. Creep Damage

The allowable duration T_d , from Fig. I-14.6 A
Code Case 1592

$$T_d = 6 \times 10^4 \text{ Hrs.}$$

the cycle duration of transient 100 Hrs. (Assumed)

the creep damage per cycle

$$\frac{t}{T_d} = \frac{100}{6 \times 10^4} = 0.0017$$

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Creep-Fatigue Damage

2. Fatigue Damage

Element 412 @ shaft @ transient E-207

$$\epsilon_t = 40.9 \times 10^3 / 22.9 \times 10^6 = 0.001786$$

$$N_d = 2 \times 10^3 \text{ cycles} \quad (\text{Fig. T-1420-1A} \text{ code case 1592})$$

The fatigue damage fraction per cycle will be

$$\frac{n}{N_d} = \frac{1}{2 \times 10^3}$$

3. The total Creep-Fatigue Damage

$$\sum \frac{t}{T_d} + \sum \frac{n}{N_d} \leq 1$$

$$\sum \frac{t}{T_d} + \sum \frac{n}{N_d} = (6 \times 2) \frac{100}{6 \times 10^4} + (6 \times 2) \frac{1}{2 \times 10^3}$$

$$= 0.02 + 0.006$$

$$= 0.026 < 1$$

Table I-14.3A
 S_{mt} - Allowable Stress Intensity Values, 1000 psi
 Type 304 SS - 30-YS, 75-UTS (30-YS, 70-UTS)

Temp. °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
850	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
900	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
950	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.2	12.2
1000	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	13.1	11.1	9.3
1050	13.6	13.6	13.6	13.6	13.6	13.6	13.6	12.2	10.3	8.7	7.3
1100	13.2	13.2	13.2	13.2	13.2	13.2	11.5	9.7	8.2	6.8	5.7
1150	12.9	12.9	12.9	12.9	12.9	11.0	9.3	7.7	6.4	5.3	4.4
1200	12.7	12.7	12.7	12.2	10.6	8.9	7.4	6.1	5.1	4.1	3.4
1250	12.3	12.3	11.9	10.3	8.7	7.2	5.9	4.9	4.0	3.2	2.7
1300	11.9 (11.8)	11.4	10.0	8.5	7.0	5.9	4.8	3.9	3.2	2.5	2.1
1350	10.9 (10.5)	9.7	8.4	7.1	5.9	4.8	3.9	3.1	2.5	2.0	1.6
1400	9.5 (9.0)	8.1	6.9	5.9	4.8	3.9	3.1	2.5	2.0	1.6	1.2
1450	8.2 (7.5)	6.8	5.8	4.6	3.8	3.0	2.4	1.9	1.5	1.2	0.9
1500	7.0 (6.4)	5.3	4.4	3.5	2.8	2.2	1.7	1.3	1.0	0.8	0.6

Fig. I-14.3A S_{mt} - Type 304 SS

NOTE: Pages 55 to 60 from Code Case 1592. Figure Numbers omitted in this Report

CASES OF ASME BOILER AND PRESSURE VESSEL CODE

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Table I-14.5
Yield Strength Values, ¹S_y, vs. Temperature

Temp., F	304 SS	316 SS	Ni-Fe-Cr Alloy 800H	2½ Cr-1 Mo	Ni-Cr-Fe-Cb Alloy 718
(Stresses in ksi Units)					
RT	30.0	30.0	25.0	30.0	150.0
100	28.8	29.2	24.3	29.4	148.4
200	25.0	25.8	22.5	27.8	143.9
300	22.5	23.3	21.1	26.8	140.7
400	20.7	21.4	20.0	26.6	138.3
500	19.4	19.9	19.0	26.5	136.7
600	18.2	18.8	18.3	26.5	135.4
700	17.7	18.1	17.5	26.5	134.3
750	17.3	17.8	17.2	26.5	133.7
800	16.8	17.6	16.8	26.5	133.1
850	16.5	17.4	16.5	26.3	132.4
900	16.2	17.3	16.3	25.6	131.5
950	15.9	17.1	16.1	24.7	130.5
1000	15.6	17.0	15.8	23.6	129.4
1050	15.2	16.7	15.6	22.1	128.0
1100	14.7	16.5	15.3	20.4	
1150	14.4	16.4	15.0	18.4	
1200	14.1	16.2	14.8	16.1	
1250	13.7	15.8	14.5		
1300	13.2	15.3	14.3		
1350	12.5	14.9	14.0		
1400	11.6	14.4	13.7		
1450	10.6	13.8	13.4		
1500	9.5	13.1	13.0		
1550			12.3		
1600			11.0		

¹The tabulated values of yield strength are those which the Committee believes are suitable for use in design calculations required by this Case. At temperatures above room temperature the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. The yield strength values do not correspond exactly to either "average" or "minimum" as these terms are applied to a statistical treatment of a homogeneous set of data.

Neither the ASME Materials Specifications nor the rules of this Case require elevated temperature testing for yield strengths of production material for use in Code components. It is not intended that results of such tests, if performed, be compared with these tabulated yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error) further investigation by retests or other means should be considered.

Table I-14.6A
Expected Minimum Stress-to-Rupture Values, 1000 psi
Type 304 SS

Temp., °F	1 hr	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
800	57	57	57	57	57	57	57	57	51	44.3	39
850	56.5	56.5	56.5	56.5	56.5	56.5	50.2	45.4	40	34.7	30.5
900	55.5	55.5	55.5	55.5	51.5	46.9	41.2	36.1	31.5	27.2	24
950	54.2	54.2	51	48.1	43	38.0	33.5	28.8	24.9	21.2	18.3
1000	52.5	50	44.5	39.8	35	30.9	26.5	22.9	19.7	16.6	14.0
1050	50	41.9	37	32.9	28.9	25.0	21.6	18.2	15.5	13.0	11.0
1100	45	35.2	31	27.2	23.9	20.3	17.3	14.5	12.3	10.2	8.6
1150	38	29.5	26	22.5	19.3	16.5	13.9	11.6	9.6	8.0	6.6
1200	32	24.7	21.5	18.6	15.9	13.4	11.1	9.2	7.6	6.2	5.0
1250	27	20.7	17.9	15.4	13	10.8	8.9	7.3	6.0	4.9	4.0
1300	23	17.4	15	12.7	10.5	8.8	7.2	5.8	4.8	3.8	3.1
1350	19.5	14.6	12.6	10.6	8.8	7.2	5.8	4.6	3.8	3.0	2.4
1400	16.5	12.1	10.3	8.8	7.2	5.8	4.7	3.7	3.0	2.3	1.9
1450	14.0	10.2	8.8	7.3	5.8	4.6	3.8	2.9	2.3	1.8	1.4
1500	12.0	8.6	7.2	6.0	4.9	3.8	3.0	2.4	1.8	1.4	1.1

Fig. I-14.6A Stress-to-rupture (minimum)

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Table I-14.7
Modulus of Elasticity vs. Temperature

Temp., °F	(Static) Modulus of Elasticity, psi $\times 10^{-4}$			
	304 SS and 316 SS	Ni-Fe-Cr Alloy 800H	2% Cr - 1 Mo	Ni-Cr-Fe-Cb Alloy 718
70	28.3	28.5	29.9	—
100	—	—	—	29.0
200	27.7	27.8	29.5	28.38
300	27.1	27.3	29.0	27.93
400	26.6	26.8	28.6	27.51
500	26.1	26.3	28.0	27.10
600	25.4	25.7	27.4	26.69
700	24.8	25.2	26.6	26.26
750	—	—	—	—
800	24.1	24.6	25.7	25.82
850	23.7	24.4	—	—
900	23.3	24.1	24.5	25.35
950	22.9	23.8	—	—
1000	22.5	23.5	23.0	24.84
1050	22.1	23.3	—	24.56
1100	21.7	22.9	20.4	—
1150	21.3	22.7	—	—
1200	20.9	22.4	15.6	—
1250	20.5	22.1	—	—
1300	20.1	21.7	—	—
1350	19.7	21.4	—	—
1400	19.2	21.1	—	—
1450	18.7	20.7	—	—
1500	18.3	20.3	—	—
1550	—	19.8	—	—
1600	—	19.2	—	—

Fig. T-1430-1A, 1B Design fatigue strain range, ϵ_f , 304 SS and 316 SS — elastic analysis

Table T-1430-1A, 1B

Design Fatigue Strain Range, ϵ_f , for 304 SS and 316 SS
(Elastic Analysis)

N_d Number of Cycles	ϵ_f , Strain Range (in./in.) at Temperature				
	800 F	850 F	900 F	950 F	1000-1200 F
10^1	.0448	.0303	.0201	.0137	.00915
2×10^1	.0318	.020	.0124	.0078	.00472
4×10^1	.0231	.0145	.00867	.0051	.00322
10^2	.0168	.00982	.00587	.00355	.00212
2×10^2	.0125	.00772	.00469	.0028	.00174
4×10^2	.00956	.00612	.00387	.0024	.00152
10^3	.00711	.00462	.00304	.00198	.00129
2×10^3	.00576	.00382	.00257	.00173	.00114
4×10^3	.00476	.00322	.00222	.00153	.00104
10^4	.00376	.00261	.00186	.0013	.000922
2×10^4	.00316	.00222	.00164	.00116	.000842
4×10^4	.00269	.00202	.00144	.00106	.000762
10^5	.00224	.00162	.00122	.000899	.000662
2×10^5	.00196	.00147	.00108	.000799	.000602
4×10^5	.00176	.00131	.000966	.000719	.000544
10^6	.00151	.00112	.000826	.000619	.000482

CASES OF ASME BOILER AND PRESSURE VESSEL CODE

Fig. T-1800-A-4 Average isochronous stress-strain curves

APPENDIX B

THERMAL DEFORMATION ANALYSIS

Figure

- B-1 APSA Model for Static Assembly
- B-2 APSA Model for Rotating Assembly
- B-3 Finite Element Model @ Bearing Area - Node No.
- B-4 Finite Element Model @ Bearing Area - Element No.
- B-5 Finite Element Model @ Bearing Area - Node No.
- B-6 Finite Element Model @ Bearing Area - Element No.

THERMAL DEFORMATION ANALYSIS

The finite element computer program (APSA) has been used to determine the deflection of pump component during thermal transient events. As described in Section 3 of this report, the worst-time slices with maximum temperature difference (ΔT) were obtained through the iteration of the temperature time-history process. The worst-time slices for each transient were used in the stress-deformation model to determine the clearance change between all critical components. Figure B-1 through Figure B-12 showed the APSA stress model of nodes and element for various parts of the inducer-impeller assembly. Table B-1 through Table B-36 indicated the calculation of clearance from computer output for pump elements.

INTERMEDIA SODIUM INDUCER PUMP --- BOWL (APSA MODEL)
UNDEFORMED STRUCTURE

*0719083
040979 0002
AXISYMMETRIC ANALYSIS

FIG B-1 APSA MODEL
STATIC ASSEMBLY

INTERMEDIATE SODIUM INDUCER PUMP — PUMP SHAFT REGION
UNDEFORMED STRUCTURE

*0719083
033079 0002
AXISYMMETRIC ANALYSIS

FIG. B-2 APSA MODEL

ROTATING ASSEMBLY

FIG.83 FINITE ELEMENT MODEL

NODE POINT NUMBER

FIG. B-4 FINITE ELEMENT MODEL

ELEMENT NUMBER

FIG. B-5 FINITE ELEMENT MODEL

— NODE POINT NUMBER

FIG.B-8 FINITE ELEMENT MODEL
ELEMENT NUMBER

FIG. B-9 FINITE ELEMENT MODEL
NODE POINT NUMBER

FIG. B-10 FINITE ELEMENT MODEL

ELEMENT NUMBER

FIG. B-11 FINITE ELEMENT MODEL

NODE POINT NUMBER

FIG.B-12 FINITE ELEMENT MODEL
ELEMENT NUMBER

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TABLE B-1

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E20?
(MILS)

* NODES	TIME = 100 SEC.			TIME = 280 SEC.		
STA.-	STATIC-ROTATING=(Δ)			STATIC-ROTATING=(Δ)		
145-328	38.7	36.3	+2.4	34.5	32.8	+1.7
193-350	38.8	37.4	+1.4	35.6	33.8	+1.8
239-361	39.7	37.9	+1.8	35.8	34.6	+1.2
287-372	39.0	38.0	+1.0	32.9	34.9	+2.0
331-383	38.5	37.5	+1.0	33.5	34.3	+0.8
350-394	36.9	35.9	+1.0	32.3	33.0	+0.5
369-405	36.4	34.5	+1.9	32.2	32.0	+0.2
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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TABLE B-2

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E203
(MILS)

* NODES STA.-	TIME = 100 SEC.			TIME = 280 SEC.		
	STATIC-ROTATING = (Δ)			STATIC -ROTATING = (Δ)		
145-328	24.9	26.6	-1.7	29.0	30.1	-1.1
193-350	24.8	25.5	-0.7	27.9	29.0	-1.1
239-361	26.0	25.1	+0.9	29.8	28.3	-1.5
287-372	26.7	25.0	+1.7	31.6	28.0	+3.6
331-383	27.2	25.4	+1.8	32.2	28.5	+3.7
350-394	26.6	27.0	-0.4	31.1	29.9	+1.2
369-405	27.1	28.4	-1.3	31.2	30.9	+0.3
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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TABLE B-3

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E204
(MILS)

* NODES	TIME = 100 SEC.			TIME = 210 SEC.		
STA.-	STATIC-ROTATING=(Δ)			STATIC-ROTATING=(Δ)		
145-328	44.7	41.6	+3.1	40.8	38.0	+2.8
193-350	44.9	43.1	+1.8	42.1	39.7	+2.4
239-361	45.9	43.8	+2.1	42.2	40.8	+1.4
287-372	44.9	43.9	+1.0	39.7	41.1	-1.4
331-383	44.3	43.2	+1.0	38.9	40.3	-1.4
350-394	42.3	41.1	+1.2	37.4	38.2	-0.8
369-405	41.7	39.1	+2.6	37.2	36.5	+0.7
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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TABLE B-4

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E207
 (MILS)

* NODES STA.-	TIME = 275 SEC.			TIME = 385 SEC.		
	STATIC-ROTATING=(Δ)			STATIC-ROTATING=(Δ)		
145-328	45.7	41.1	+4.6	41.1	37.4	+3.7
193-350	47.2	43.7	+3.5	43.4	39.6	+3.8
239-361	47.0	45.3	+1.7	42.8	41.3	+1.5
287-372	43.8	45.7	-1.9	38.9	41.8	-2.9
331-383	42.6	44.5	-1.9	37.7	40.7	-3.0
350-394	40.8	41.0	-0.2	36.3	37.7	-1.4
369-405	40.2	38.3	+3.5	36.0	35.6	+0.4
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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TABLE B-5

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E208
(MILS)

* NODES	TIME = 115 SEC.			TIME = 240 SEC.		
STA.-	STATIC-ROTATING=(Δ)			STATIC-ROTATING=(Δ)		
145-328	50.7	47.0	+3.7	45.9	42.8	+3.1
193-350	51.0	48.8	+2.2	47.5	44.6	+2.9
239-361	52.0	49.6	+2.4	47.5	45.9	+1.6
287-372	50.6	49.8	-0.8	44.6	46.2	-1.6
331-383	49.9	49.0	-0.9	43.7	45.4	-1.7
350-394	47.7	46.5	-1.2	42.1	40.0	-0.9
369-405	47.0	44.2	+2.8	41.9	41.3	+0.6
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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TABLE B-6

RADIAL CLEARANCE CHANGE
TEST TRANSIENT E210
(MILS)

* NODES	TIME = 50 SEC.			TIME = 150 SEC.		
STA.-ROT.	STATIC-ROTATING=(Δ)			STATIC-ROTATING=(Δ)		
145-328	52.1	49.9	+ 2.2	49.3	46.7	+ 2.6
193-350	52.0	50.8	+ 1.2	50.1	48.1	+ 2.0
239-361	53.7	51.1	+ 2.6	50.8	48.9	+ 1.9
287-372	53.5	51.1	+ 2.4	48.9	49.1	- 0.2
331-383	53.1	50.7	+ 2.4	48.3	48.5	- 0.2
350-394	50.9	49.3	+ 1.6	46.6	46.7	- 0.1
369-405	50.3	47.9	+ 2.4	46.3	45.3	+ 1.0
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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TABLE B-7

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E202
 (MILS)

* NODES	TIME = 100 SEC.			TIME = 280 SEC.		
STA.-STA.	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
765-694	67.9	59.2	+ 8.7	60.7	56.5	+ 4.2
772-731	67.7	60.8	+ 6.9	60.5	56.7	+ 3.8
770-729	62.9	56.3	+ 6.6	56.3	52.8	+ 3.5
782-742	63.1	56.7	+ 6.4	56.4	52.8	+ 3.6
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-11

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TABLE B-8

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E203
 (MILS)

* NODES	TIME = 100 SEC.			TIME = 280 SEC.		
STA.-STA.	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
765-694	52.3	58.4	-6.1	59.4	61.1	-1.7
772-731	52.3	56.8	-4.5	59.5	60.8	-1.3
770-729	48.3	53.0	-4.7	55.0	56.6	-1.6
782-742	48.1	52.7	-4.6	54.7	56.5	-1.8
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-11

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TABLE B-9

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E204
 (MILS)

* NODES STA.-STA.	TIME = 100 SEC.	TIME = 210 SEC.
	OUTER - INNER = (Δ)	OUTER - INNER = (Δ)
765-694	77.6 66.0 + 11.6	69.8 62.6 + 7.2
772-731	77.6 68.1 + 9.5	69.8 63.1 + 6.7
770-729	72.2 63.1 + 9.1	65.0 58.7 + 6.3
782-742	72.6 63.6 + 9.0	65.5 58.8 + 6.7
-		
-		
-		
-		

* LOCATIONS EXHIBITED IN FIG. B-11

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TABLE B-10

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E207
(MILS)

* NODES	TIME = 275 SEC.			TIME = 385 SEC.		
STA.-STA.	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
765-694	74.6	61.8	+13.0	67.3	59.4	+ 7.9
772-731	74.5	63.6	+ 10.9	67.1	60.0	+ 7.1
770-729	69.5	58.9	+ 10.6	62.6	55.7	+ 6.9
782-742	70.2	59.4	+ 10.8	63.1	55.9	+ 7.2
—						
—						
—						
—						

* LOCATIONS EXHIBITED IN FIG. B-11

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TABLE B-11

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E208
(MILS)

* NODES STA.-STA.	TIME = 115 SEC.			TIME = 240 SEC.		
	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
765-694	87.5	74.4	+ 13.1	78.6	71.2	+ 7.4
772-731	87.5	76.7	+ 10.8	78.6	71.7	+ 6.9
770-729	81.4	71.1	+ 10.3	73.2	66.7	+ 6.5
782-742	81.8	71.6	+ 10.2	73.7	66.8	+ 6.9
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-11

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TABLE B-12

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E210
 (MILS)

* NODES	TIME = 50 SEC.			TIME = 150 SEC.		
STA.-STA.	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
765-694	94.6	84.1	+10.5	87.0	79.9	+7.1
772-731	94.7	86.3	+8.4	87.0	80.5	+6.5
770-729	87.9	80.0	+7.9	80.9	74.8	+6.1
782-742	88.0	80.5	+7.5	81.3	75.0	+6.3
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-11

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TABLE B-13

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E202
(MILS)

* NODES	TIME = 100 SEC.	TIME = 280 SEC.
STA.- ROT.	STATIC-ROTATING = (Δ)	STATIC-ROTATING = (Δ)
633 - 659	62.0 62.1 - 0.1	59.5 58.2 + 1.3
653 - 658	61.1 60.2 + 0.9	58.5 56.7 + 1.8
-		
-		
-		
-		
-		
-		

* LOCATIONS EXHIBITED IN FIG. B-7

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TABLE B-14

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E203
 (MILS)

* NODES STA.- ROT.	TIME = 100 SEC.			TIME = 280 SEC.		
	STATIC-ROTATING = (Δ)			STATIC-ROTATING = (Δ)		
633 - 659	62.2	57.0	+ 5.2	64.6	60.9	+ 3.7
653 - 658	60.8	56.2	+ 4.6	63.4	59.8	+ 3.6
-						
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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TABLE B-15

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E204
 (MILS)

* NODES STA.-ROT.	TIME = 100 SEC.			TIME = 210 SEC.		
	STATIC-ROTATING = (Δ)			STATIC-ROTATING = (Δ)		
633 - 659	69.0	69.7	-0.7	65.8	65.6	+0.2
653 - 658	68.1	67.5	+0.6	64.8	63.7	+1.1
-						
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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MODEL NO.

TABLE B-16

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E207
(MILS)

* NODES STA.-ROT.	TIME = 275 SEC.			TIME = 385 SEC.		
	STATIC-ROTATING = (Δ)			STATIC-ROTATING = (Δ)		
633 - 659	64.6	66.1	-1.5	62.4	62.3	+0.1
653 - 658	63.8	63.9	-0.1	61.5	60.4	+1.1
-						
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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TABLE B-17

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E208
(MILS)

* NODES	TIME = 115 SEC.			TIME = 240 SEC.		
STA.- ROT.	STATIC-ROTATING = (Δ)			STATIC-ROTATING = (Δ)		
633 - 659	77.8	78.7	-0.9	74.9	74.2	+0.7
653 - 658	76.8	76.2	+0.6	73.8	72.1	+1.7
-						
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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91

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MODEL NO.

TABLE B-18

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E210
(MILS)

* NODES STA.-ROT.	TIME = 50 SEC.			TIME = 150 SEC.		
	STATIC-ROTATING = (Δ)			STATIC-ROTATING = (Δ)		
633 - 659	88.2	86.9	+1.3	84.1	82.9	+1.2
653 - 658	86.9	84.3	+2.6	82.7	80.7	+2.0
-						
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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DATE:		MODEL NO.

TABLE B-19

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E202
(MILS)

* NODES STA.-ROT.	TIME = 100 SEC.			TIME = 280 SEC.		
	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
410 - 464	61.6	54.9	+6.7	54.7	51.5	+3.2
446 - 481	60.6	56.9	+3.7	55.7	53.2	+2.5
463 - 499	59.7	58.5	+1.2	55.9	54.6	+1.3
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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93

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DATE:

MODEL NO.

TABLE B-20

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E203
(MILS)

* NODES	TIME = 100 SEC.			TIME = 280 SEC.		
STA.-ROT.	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
410 - 464	42.9	50.1	-7.2	49.7	53.5	-3.8
446 - 481	50.9	51.3	-0.4	55.9	55.0	+0.9
463 - 499	55.1	52.5	+2.6	58.9	56.4	+2.5
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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94

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DATE:

MODEL NO.

TABLE B-21

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E204
(MILS)

* NODES	TIME = 100 SEC.			TIME = 210 SEC.		
STA.-ROT.	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
410 - 464	70.8	61.6	+9.2	64.3	57.9	+6.4
446 - 481	68.6	64.1	+4.5	63.5	60.0	+3.5
463 - 499	66.9	65.8	+1.1	62.7	61.5	+1.2
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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95

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DATE:

MODEL NO.

TABLE B-22

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E207
(MILS)

* NODES STA.-ROT.	TIME = 275 SEC.			TIME = 385 SEC.		
	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
410 - 464	70.4	58.6	+11.8	62.9	55.4	+7.5
446 - 481	66.0	61.0	+5.0	61.1	57.3	+3.8
463 - 499	63.2	62.6	+0.6	59.8	58.8	+1.0
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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96

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DATE:

MODEL NO.

TABLE B-23

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E20 B
(MILS)

* NODES STA.-ROT.	TIME = 115 SEC.			TIME = 240 SEC.		
	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
410 - 464	80.1	69.5	+10.6	72.1	65.6	+6.5
446 - 481	77.5	72.2	+5.3	71.7	67.9	+3.8
463 - 499	75.4	74.1	+1.3	71.0	69.6	+1.4
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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97

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MODEL NO.

TABLE B-24

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E210
(MILS)

* NODES	TIME = 50 SEC.			TIME = 150 SEC.		
	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
410 - 464	83.8	77.2	+6.6	78.9	73.1	+5.8
446 - 481	84.2	80.0	+4.2	79.6	75.6	+4.0
463 - 499	83.8	82.0	+1.8	79.5	77.6	+1.9
-						
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-7

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DATE:		REPORT NO.
		MODEL NO.

TABLE B-25

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E202
(MILS)

* NODES	TIME = 100 SEC.			TIME = 280 SEC.		
STA.-ROT.	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
630-677	50.3	51.3	-1.0	49.2	49.2	0.0
648-691	51.3	51.6	-0.3	49.3	49.2	+0.1
727-705	53.0	51.7	+1.0	49.6	49.2	+0.4
751-761	52.4	50.9	+2.0	49.4	49.1	+0.3
758-886	50.3	50.3	0	49.1	48.9	+0.2
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-9

CHECKED BY:	Energy Systems Group	TABLE NO. N266SR000002
DATE:		99
		MODEL NO.

TABLE B-26

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E203
 (MILS)

* NODES STA.-ROT.	TIME = 100 SEC.			TIME = 280 SEC.		
	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
630-677	52.5	49.6	+2.9	53.6	52.9	+0.7
648-691	51.5	49.9	+1.6	53.4	52.9	+0.5
727-705	49.8	50.0	-0.2	53.2	52.9	+0.3
751-761	50.4	50.4	0.0	53.2	52.9	+0.3
758-886	52.5	51.5	+1.0	53.5	53.1	+0.4
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-9

TABLE B-27

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E204
 (MILS)

* NODES	TIME = 100 SEC.			TIME = 210 SEC.		
STA.-ROT.	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
630-677	55.7	59.0	-3.3	54.3	55.2	-0.9
648-691	57.1	58.6	-1.5	54.6	55.1	-0.5
727-705	59.4	58.5	+0.9	55.2	55.1	+0.1
751-761	58.6	57.8	+0.8	55.1	55.0	+0.1
758-886	55.7	56.2	-0.5	54.4	54.4	0.0
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-9

TABLE B-28

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E207
 (MILS)

* NODES	TIME = 275 SEC.			TIME = 385 SEC.		
STA.-ROT.	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
630-677	52.4	55.3	-2.9	51.4	52.2	-0.8
648-691	53.5	55.0	-1.5	51.8	52.2	-0.4
727-705	55.4	55.0	+0.4	52.4	52.3	+0.1
751-761	54.8	54.5	+0.3	52.3	52.2	+0.1
758-886	52.5	53.0	-0.5	51.6	51.6	0.0
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-9

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		MODEL NO.

TABLE B-29

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E208
(MILS)

* NODES	TIME = 115 SEC.			TIME = 240 SEC.		
STA.-ROT.	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
630-677	62.9	66.6	-3.7	61.8	62.6	-0.8
648-691	64.5	66.1	-1.6	62.1	62.5	-0.4
727-705	66.9	66.0	+0.9	62.7	62.5	+0.2
751-761	66.0	65.3	+0.7	62.6	62.4	+0.2
758-886	63.0	63.6	-0.6	62.0	61.9	+0.1
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-9

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TABLE B-30

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E210
(MILS)

* NODES	TIME = 50 SEC.			TIME = 150 SEC.		
STA.-ROT.	STATIC - ROTATING = (Δ)			STATIC - ROTATING = (Δ)		
630-677	71.3	74.3	-3.0	69.4	70.3	-0.9
648-691	72.9	73.8	-0.9	69.7	70.2	-0.5
727-705	75.3	73.7	-1.6	70.3	70.2	+0.1
751-761	74.3	73.0	-1.3	70.1	70.0	+0.1
758-886	71.1	71.5	-0.4	69.5	69.4	+0.1
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-9

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DATE:		MODEL NO.

TABLE B-31

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E202
(MILS)

* NODES STA.-STA.	TIME = SEC.			TIME = SEC.		
	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
267-266	51.0	47.7	+3.3	47.4	42.0	+5.4
291-290	50.9	47.4	+3.5	47.5	41.4	+6.1
335-334	50.1	47.0	+3.1	46.1	40.8	+5.3
374-373	50.1	45.6	+4.5	44.8	40.5	+4.3
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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105

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TABLE B-32

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E203
(MILS)

* NODES	TIME = 100 SEC.			TIME = 280 SEC.		
STA.-STA.	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
267-266	32.3	32.3	0.0	35.7	37.9	-2.2
291-290	32.4	32.6	-0.2	35.6	38.5	-2.9
335-334	33.1	33.0	+0.1	37.0	39.1	-2.1
374-373	33.0	34.3	-1.3	38.3	39.4	-1.1
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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106

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DATE:

MODEL NO.

TABLE B-33

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E204
(MILS)

* NODES	TIME = 100 SEC.			TIME = 210 SEC.		
STA.-STA.	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
267-266	59.1	54.9	+4.2	56.0	49.0	+6.9
291-290	58.9	54.6	+4.3	56.1	48.1	+8.0
335-334	57.9	54.0	+3.9	54.4	47.4	+7.0
374-373	57.9	52.2	+5.7	53.1	46.6	+6.5
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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TABLE B-34

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E207
(MILS)

* NODES	TIME = 275 SEC.			TIME = 385 SEC.		
STA.-STA.	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
267-266	63.0	54.4	+8.4	58.5	48.6	+9.9
291-290	63.0	53.2	+9.8	58.7	47.1	+11.6
335-334	60.4	52.1	+8.3	55.5	46.0	+9.5
374-373	58.9	50.3	+8.6	52.8	45.2	+7.2
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-3

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108

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TABLE B-35

RADIAL CLEARANCE CHANGE (Δ)
TEST TRANSIENT E208
(MILS)

* NODES	TIME = 115 SEC.			TIME = 240 SEC.		
STA.-STA.	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
267-266	67.1	62.0	+5.1	63.2	55.2	+8.0
291-290	67.0	61.5	+5.5	63.3	54.1	+9.2
335-334	65.7	60.8	+4.9	61.3	53.3	+8.0
374-373	65.6	58.8	+6.8	59.6	52.6	+7.0
—						
—						
—						
—						

* LOCATIONS EXHIBITED IN FIG. B-3

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TABLE B-36

RADIAL CLEARANCE CHANGE (Δ)
 TEST TRANSIENT E210
 (MILS)

* NODES STA.-STA.	TIME = 50 SEC.			TIME = 150 SEC.		
	OUTER - INNER = (Δ)			OUTER - INNER = (Δ)		
267-266	68.2	65.1	+3.1	66.2	60.2	+6.0
291-290	68.1	65.0	+3.1	66.2	59.8	+6.4
335-334	67.4	64.7	+2.7	65.0	58.9	+6.1
374-373	67.8	63.1	+4.7	64.2	58.1	+6.1
-						
-						
-						
-						

* LOCATIONS EXHIBITED IN FIG. B-3

FIG. B-13

46 1240

20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1240

K&S 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIG. B-15

46 1240

K&E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIG. B-17

46 1240

K&E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

INTERMEDIATE SIZE INDUCER PUMP ----- BOWL (APSA MODEL)
AXISYMMETRIC ANALYSIS STRESS-INTENSITY IS PLOTTED TAPE 10 AF1310
ISIP BOWL

*0719083
032379 0005

PLOT NO.5

FIG. B-19 . STRESS INTENSITY

(TEST TRANSIENT E-207 at 275 Seconds)

INTERMEDIATE SIZE INDUCER PUMP ----- BOWL (APSA MODEL)

AXISYMMETRIC ANALYSIS STRESS-INTENSITY IS PLOTTED TAPE 10 AF1310

ISIP BOWL

*0719093
032379 0010

PLOT NO.10

FIG. B-20 STRESS INTENSITY

(TEST TRANSIENT E-207 at 275 Seconds)

INTERMEDIATE SIZE INDUCER PUMP ----- BOWL (APSA MODEL)

AXISYMMETRIC ANALYSIS STRESS-INTENSITY IS PLOTTED TAPE ID AF1310
ISIP BOWL

*0719083
032379 0015

PLOT NO. 15

FIG. B-21 STRESS INTENSITY

(TEST TRANSIENT E-207 at 275 Seconds)

INTERMEDIATE SODIUM PUMP----SHAFT (APSA PLOT)

AXISYMMETRIC ANALYSIS STRESS-INTENSITY IS PLOTTED TAPE ID UN0182
SHAFT (BOWL)

*0719083
032379 0005

PLOT NO.5

FIG. B-22 STRESS INTENSITY

(TEST TRANSIENT E-207 at 275 Seconds)

INTERMEDIATE SODIUM PUMP---SHAFT (APSA PLOT)

AXISYMMETRIC ANALYSIS STRESS-INTENSITY IS PLOTTED TAPE ID UN0182
SHAFT (BOWL)

*0719083
032379 0010

PLOT NO.10

FIG. B-23 STRESS INTENSITY

(TEST TRANSIENT E-207 at 275 Seconds)

INTERMEDIATE SODIUM PUMP---SHAFT (APSA PLOT)

AXISYMMETRIC ANALYSIS STRESS-INTENSITY IS PLOTTED TAPE ID UN0182
SHAFT (BOWL)

*0719083
032379 0015

PLOT NO. 15

FIG. B-24 STRESS INTENSITY

(TEST TRANSIENT E-207 at 275 Seconds)

TABLE B-37

THERMAL TRANSIENTS

Transient Number*	Sodium Flow Rate (gpm)	Initial Temp. °F	Final Temp. °F	$\Sigma \Delta T$ °F	dT/dt °F/sec
201					
202	14500	750	600	-150	-1.5
203	14500	500	650	+150	+1.5
204	14500	850	650	-200	-2.0
205					
206					
207	14500	950**	620**	-330	-1.2
208	14500	950**	725**	-225	-2.0
210	14500	950**	800**	-150	-3.0

*From Specification N266ST310001, Table 4-II (Ref. 6)

** Note see Reference 9

APPENDIX C

COMPUTER PROCEDURES FOR STRUCTURAL AND THERMAL DEFORMATION ANALYSIS

References

1. J. F. Newell and S. F. Persselin, "Finite Element Axisymmetric and Planar Structural Analysis," SSME 74-1282, Rocketdyne Division, Rockwell International, Canoga Park, California 91304, April 18, 1974
2. H. C. Hsiung, "Computer Procedures to Make Thermal Stress Runs Using the APSA Computer Code," IL 600-77-216, Atomics International Division, Rockwell International, Canoga Park, California 91306, June 13, 1977

In the evaluation of structural and thermal deformation analyses for ISIP, APSA-Mark Interface Computer Code has been utilized to input thermal transient data into APSA finite element program. TAP (Thermal Analysis Program) was used to determine critical temperature difference (ΔT) through the time-history iteration of each transient for various cross section of pump components. The critical temperature field and time slices of each transient were then used as input for calculating thermal stress and deflection in APSA program. Figure C1 shows the flow chart of computer procedure used. The basic purpose using APSA-Mark Interface Computer Code was that the two programs have different purposes of usage. The computer input cards setup is shown in Figures C2, C3, and C4. Figure C2 shows the coordinates input of temperature field nodes from TAP tape into APSA tape File 1. Figure C3 is the setup for storing TAP temperature field and time slices in APSA tape File 2. APSA finite element model uses the temperature time slice from File 2 for determining the stress and deflection as shown in Figure C4.

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Note:

The APSA input tape contains the temperature field history data of the selected transients, while the output tape contains the thermal stress analysis results.

FIGURE C1- Flow Chart of Computer Procedures to Use the APSA Code for Thermal Stress Analysis

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* JESJCL JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL JF

```
//WCA09020 JOB 'LOFFREDO' AI731160*0719083 005 9990005 37', *
// REGION=200K,TIME=1
// *MAIN TAPEAUTH=WDY
// *FORMAT PR,DDNAME=JES10001,CONTROL=SINGLE,OVFL=UN
// *DSN=ISI.PUMP.GEOM.DISC=MESH GEOM. TAP
// EXEC PG4=TEBGENER
//SYSIN DD DUMMY
//SYSPRINT DD SYSOUT=A
//SYSUT2 DD UNIT=3400-3,DISP=(NEW,KEEP,DELETE),DSN=ISI.PUMP.GEOM,
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=6400)
//SYSUT1 DD *
BLANK CARD
( TEMPERATURE NODES COORDINATE CARDS FOLLOW THE BLANK CARD)
```

NOTE: THE UNDERLINED PORTION OF THE JCL
HAS TO BE MODIFIED FOR EACH CASE

FIG C-2 JCL SETUP

(TAP CORDINATES STORE IN APSA TAPE FILE 1)

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MODEL NO.

 * JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL JFSJCL

//WCA09027 JOB 'LOFFREDDI AI731160*6719083 005 9990005 37', *

// REGION=500K, TIME=1

/*FORMAT PR, DDNAME=JESI001, CONTROL= SINGLE, OVFL=ON

//STPL EXFL @FLINK

//L.SYSIN DD DSN=WW025.APSAMARK.OBJECT, DISP=SHR

//G.FT01F001 DD UNIT=2400-3, DISP=(OLD, KEEP, KEEP), DCH=BUFNO=1,

// VOL=SER=AF0304, LABEL=(1, SL), DSN=ISI.PUMP.GEOM

//G.FT11F001 DD DISP=(NEW, KEEP, DELETE), VOL=REF=*.FT01F001, LABEL=(2, SL),

// DCH=(REF, FM=VRS, BLKSIZE=13030, BUFNO=1), DSN=ISI.PUMP.WNFLW

//G.FT09F001 DD UNIT=2400-3, DISP=(OLD, KEEP, KEEP), DCH=BUFNO=1,

// VOL=SER=UHR878, LABEL=(1, SL), DSN=ISIP.E202

//G.SYSIN DD * (APSAMARC IOPTH=2 INPUT DECK FOLLOWS THIS CARD)

INTERMEDIATE SIZE INDUCER PUMP

2 643 1 600

/*

FIG C-3 JCL SETUP

(TAP TEMPERATURE FIELD STORE IN APSA TAPE FILE 2)

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DATE:		MODEL NO.

```
*****
* JESJCL JESJCL JFSJCL JESJCL JFSJCL JESJCL JFSJCL JESJCL JESJCL JFSJCL
*****
```

```
//WCA12070 JOB 'LOFFREDO AI731160*0719083 005 9990032 37', *
// REGION=800K,TIME=5
//*MAIN TAPEAUTH=WOY
/*FORMAT PR,FORMS=STAND=SW,DDNAME=FT06F001
/*FORMAT PR,DDNAME=JESI0001,CONTROL=SINGLE,OVFL=ON
/*FORMAT PR,DDNAME=JESI0002,CONTROL=SINGLE,OVFL=ON
// EXEC KAPSA,PLOTDSN='ISI.PUMP',DISP=PASS
//A,FT20F001 DD VOL=SER=AF0304,LABEL=(2,SL),DSN=ISI.PUMP.WNFLW
//SYSIN DD *
// EXEC KAPSAPLT,PLOTDSN='ISI.PUMP'
//SYSIN DD *
```

INTERMEDIATE SIZE INDUCER PUMP --- PUMP SHAFT

-1 3 -280 70.

(BLANK CARD) (APSA STRESS MODEL CARDS FOLLOW THIS BLANK CARD)

FIG. C-4 JCL SETUP
(APSA STRESS MODEL UTILIZE TEMPERATURE DATA IN FILE 2)

PREPARED BY:	Rockwell International Energy Systems Group	N266SR000002 128
CHECKED BY:		
DATE:	MODEL NO.	