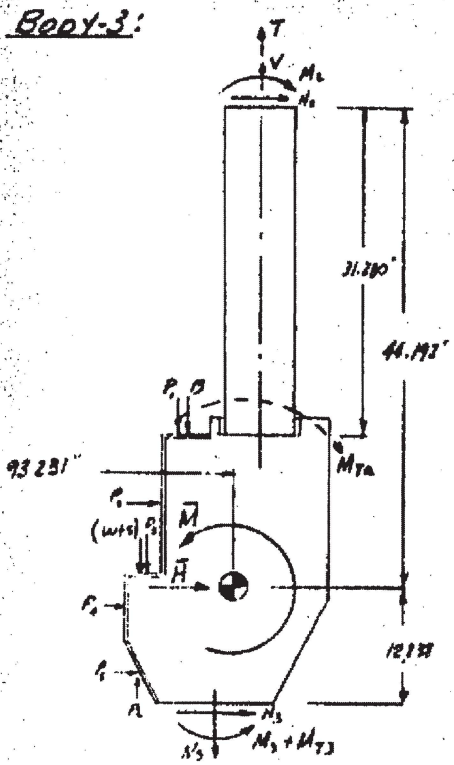
5. DETAILED ANALYSIS:

d. DEVELOPMENT OF CONTINUITY EQUATIONS:

2. MOVEMENTS DUE TO LOADS:

BODY-3:



$I = 20945 \text{ in}^4$

$A = 378.957 \text{ in}^2$

$\frac{R^2}{I} = 0.41409$

$\frac{R^2}{A} = 22.9367$

$\bar{H} = 1.0290 H_2 + 0.9764 H_3 + 23.7340 P$

$\bar{M} = -45.4751 H_2 - 1.0290 H_2 - 1.0136 M_{T4} + 12.5351 H_2 + 0.9765 (M_3 + M_{T3}) + 7.1372 (T+V) + 7.8499 (W+S) - 79.8729 P$

Δ° & δ° / $\Delta\phi$

DISPLACEMENTS DUE TO REDUNDANT FORCES:

$E\Delta_{12} = \frac{R^2}{A}\bar{H} - h_1 \frac{R^2}{I}\bar{M} = 1919.0093 H_2 + 69.7697 M_2 - 207.4870 H_3 - 17.9066 M_3 - 130.8935 V$

$E\Delta^{\circ}_{12} = \frac{R^2}{I}\bar{M} = -69.7697 H_2 - 3.6815 M_2 + 5.2019 H_3 + 0.4052 M_3 + 2.9619 V$

$E\Delta_{33} = \frac{R^2}{A}\bar{H} - h_3 \frac{R^2}{I}\bar{M} = -218.6730 H_2 - 5.4818 H_2 + 89.1774 H_3 + 5.2020 M_3 + 38.0249 V$

$E\Delta^{\circ}_{33} = \frac{R^2}{I}\bar{M} = -19.8717 H_2 - 0.4270 M_2 + 5.2019 H_3 + 0.4052 M_3 + 2.9619 V$

$E V_{33} = 6.436 \frac{R^2}{I}\bar{M} = -130.8941 H_2 - 2.9617 M_2 + 36.0804 H_3 + 2.8105 M_3 + 30.1482 V$

5. DETAILED ANALYSIS:

d. DEVELOPMENT OF CONTINUITY EQUATIONS:

2. MOVEMENTS DUE TO FORCES:

DISPLACEMENTS DUE TO APPLIED FORCES:

$$E\delta_{32} = \frac{R^2}{A}\bar{H} - h_j\frac{R^2}{I}\bar{M} = -130.8923T - 143.9612(W+S) + 2009.1891P$$

$$E\delta_{32}^{\phi} = \frac{R^2}{I}\bar{M} = 2.9619T + 3.2576(W+S) - 33.1465P$$

$$E\delta_{33} = \frac{R^2}{A}\bar{H} - h_j\frac{R^2}{I}\bar{M} = 39.0249T + 41.8215(W+S) + 118.8449P$$

$$E\delta_{33}^{\phi} = \frac{R^2}{I}\bar{M} = 2.9619T + 3.2576(W+S) - 33.1465P$$

$$Ev_{32} = 6.936\frac{R^2}{I}\bar{M} = -229.9041P$$

DISPLACEMENTS DUE TO THERMAL EFFECTS:

$$E\delta_{32T} = R_3E\alpha(T_m - 70) - R_3h_1E\alpha\left(\frac{\Delta T}{\Delta X}\right)_{eq} - h_j\frac{R^2}{I}\bar{M} =$$

$$= 93.231E\alpha(T_m - 70) - 4120.064E\alpha\left(\frac{\Delta T}{\Delta X}\right)_{eq} - 17.9066M_{T3} + 18.5485M_{T4}$$

$$E\delta_{32T}^{\phi} = R_3E\alpha\left(\frac{\Delta T}{\Delta X}\right)_{eq} + \frac{R^2}{I}\bar{M} = 93.231E\alpha\left(\frac{\Delta T}{\Delta X}\right)_{eq} + 0.4052M_{T3} - 0.41972M_{T4}$$

$$E\delta_{33T} = R_4E\alpha(T_{beq} - 70) + h_j\frac{R^2}{I}\bar{M} = 91.031E\alpha(T_{beq} - 70) + 5.2020M_{T3} - 5.3884M_{T4}$$

$$E\delta_{33T}^{\phi} = R_3E\alpha\left(\frac{\Delta T}{\Delta X}\right)_{eq} + \frac{R^2}{I}\bar{M} = 93.231E\alpha\left(\frac{\Delta T}{\Delta X}\right)_{eq} + 0.4052M_{T3} - 0.41972M_{T4}$$

$$Ev_{32T} = l_B E\alpha(T_B - 70)\frac{E\alpha_{sp}}{E\alpha_{eq}} + 6.936\frac{R^2}{I}\bar{M} =$$

$$= 30.6221E\alpha(T_B - 70) + 646.6502E\alpha\left(\frac{\Delta T}{\Delta X}\right)_{eq} + 2.8105M_{T3} - 2.9112M_{T4}$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION: FATIGUE EVALUATION OF HEAD FLANGE VESSEL FLANGE AND CLOSURE STUDS

NUMBER S-131-P A67
SHEET 16 OF 51
DATE 5-12-66 BY CALDWELL
CHECK DATE 5-12-66 BY ALEXANDER

5. DETAILED ANALYSIS:
d. DEVELOPMENT OF CONTINUITY EQUATIONS:
2. MOVEMENTS DUE TO FORCES:

$T_{a_{eq}}$, $T_{b_{eq}}$, AND $\left(\frac{\Delta T}{\Delta x}\right)_{eq}$ FOR THE VESSEL FLANGE ARE OBTAINED BY THE METHOD AS ILLUSTRATED ON SHEETS 11 & 12 AND ARE LISTED BELOW.

TRANSIENT		T_m	$(E\alpha)_i$	M_T	$\left(\frac{\Delta T}{\Delta x}\right)_{eq}$	T_a	T_b	T_b (adj.)
HEATUP	4.00 Hrs.	296	196	-2682806	6.539	211.0	381.0	172
	4.25	315	198	-2838430	6.848	226.0	401.0	183
	4.35	323	198	-2896055	6.987	232.2	413.8	187
	4.47	334	199	-2986356	7.169	240.8	427.7	194
	5.00	368	202	-3007646	7.113	275.5	460.5	220
STEADY STATE		533	212	-471993	1.066	519.2	546.8	532
COOLDOWN	4.00 Hrs	336	199	2325354	-5.582	408.6	263.4	459
	4.25	317	198	2424287	-5.849	393.0	241.0	449
	4.35	309	197	2469749	-5.989	386.9	231.1	444
	4.47	299	196	2523836	-6.151	379.0	219.0	457
	5.00	263	193	2448075	-6.059	341.8	184.2	411

SUBSTITUTING VALUES INTO EQUATIONS AS GIVEN ON SHEET - 15, WE GET THE FOLLOWING VALUES FOR DISPLACEMENTS AND ROTATIONS OF BODY-3 AT CUTS-2 & 3.

5. Detailed Analysis:

d. Development Of Continuity Matrix:

2. Movements Due To Loads:

Transient		$(T-70)$ / $(E\alpha)$	$(T-70)$ / $(E\alpha)$	$(T-70)$ / $(E\alpha)_m$	$\left(\frac{\Delta T}{\Delta \lambda}\right)_{avg}$	M_{T3}	M_{Ta}	$E\delta_{32T}$	$E\delta^{*}_{32T}$	$E\delta_{33T}$	$E\delta^{*}_{33T}$	$E\nu_{32T}$
Heatup	4.00 hrs	220 / 183	311 / 184	102 / 190	6.539	459071	1023212	9702229	-132299	2079537	-132299	-339472
	4.25	225 / 184	334 / 185	113 / 180	6.849	461449	1069229	10581097	-144324	2263799	-144324	-356069
	4.35	253 / 184	341.8 / 185	117 / 180	6.987	462890	1101081	11177955	-154725	2264701	-154725	-405380
	4.47	264 / 184	352.2 / 116	124 / 180	7.169	464736	1134218	11810278	-164762	2353930	-164762	-435043
	5.00	298 / 184	390.3 / 186	160 / 181	7.113	361170	1176806	15080433	-225563	2149524	-225563	-703782
Steadystate		463 / 186	476.8 / 186	462 / 186	1.064	17291	361003	13599949	-126063	6217775	-126063	1833059
Cooldown	4.00 hrs	268 / 184	193.8 / 182	389 / 186	-5.582	-402539	-726730	2523090	46158	5026108	46158	2549787
	4.25	249 / 184	171 / 182	379 / 186	-5.849	-406478	-774763	1579158	60142	4893324	60142	2638176
	4.55	239 / 183	166.1 / 181	374 / 186	-5.989	-408144	-796493	1129053	66740	4823010	66740	2654639
	4.47	229 / 183	149 / 181	367 / 185	-6.151	-410452	-821931	648890	73722	4748762	73722	2662044
	5.00	193 / 182	114.3 / 180	341 / 185	-6.059	-304752	-842210	-2346516	127197	4824103	127197	2880580

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION: FATIGUE EVALUATION OF HEAD FLANGE, VESSEL FLANGE AND CLOSURE STUDS

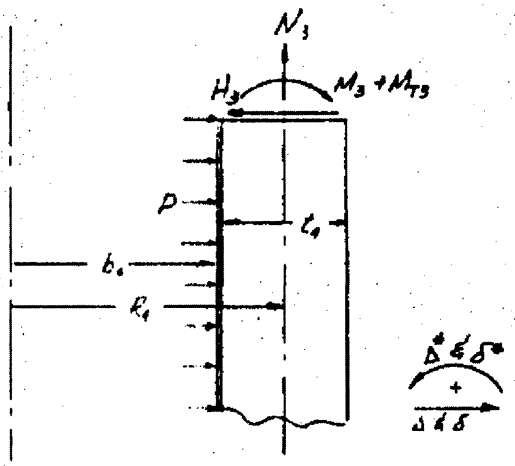
NUMBER S-151-P | A 69
SHEET 18 OF 51
DATE 5-12-66 BY CORDELL
CHECK DATE 5-12-66 BY ALEXANDER

5. DETAILED ANALYSIS:

d. DEVELOPMENT OF CONTINUITY EQUATIONS:

2. MOVEMENTS DUE TO FORCES:

BODY-4:



$R_4 = 91.031''$
$b_4 = 85.437''$
$t_4 = 10.75'$

$\beta^4 = \frac{3(1-\nu^2)}{R^2 t^2}$

$\beta = 0.04108$

$D = \frac{E t^3}{12(1-\nu^2)} = 113.76345E$

DISPLACEMENTS DUE TO REDUNDANT FORCES:

$$E\Delta_{43} = \frac{E}{2\beta^3 D}\left[-\frac{1}{\beta}H_3 + M_3\right] = -63.2918H_3 + 2.6006M_3$$

$$E\Delta^*_{43} = -\frac{E}{2\beta^2 D}\left[-H_3 + 2\beta M_3\right] = 2.6006H_3 - 0.2137M_3$$

DISPLACEMENTS DUE TO APPLIED LOADS:

$$E\delta_{43} = \frac{b_4}{t_4}\left(\frac{R_4}{b_4} - \frac{\nu}{2}\right)P = 621.6238P$$

$$E\delta^*_{43} = 0$$

DISPLACEMENTS DUE TO THERMAL EFFECTS:

$$E\delta_{43T} = R_4 E\alpha(T_{43} - 70) + \frac{E}{2\beta^2 D}M_{T3} = 91.031E\alpha(T_{43} - 70) + 2.6006M_{T3}$$

$$E\delta^*_{43T} = R_4 E\alpha\left(\frac{\Delta T}{\Delta x}\right)_{43} - \frac{E}{2\beta D}M_{T3} = 91.031E\alpha\left(\frac{\Delta T}{\Delta x}\right)_{43} - 0.2137M_{T3}$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION: FATIGUE EVALUATION OF HEAD FLANGE, VESSEL FLANGE AND CLOSURE STUDS

NUMBER S-151-P | A 70
SHEET 19 OF 31
DATE 5-12-66 BY [illegible]
CHECK DATE 5-12-66 BY ALEYALDER

5 DETAILED ANALYSIS:

d. DEVELOPMENT OF CONTINUITY EQUATIONS:

2- MOVEMENTS DUE TO FORCES:

SUBSTITUTING VALUES INTO DISPLACEMENTS AS GIVEN ON SHEET-18, WE GET THE FOLLOWING VALUES FOR DISPLACEMENTS AND ROTATIONS OF BODY-1 AT CUT-3.

TRANSIENT		T_{43}	$(E\alpha)_m$	$\left(\frac{\Delta T}{\Delta x}\right)_{43}$	M_{T3}	$E\delta_{43T}$	$E\delta^*_{43T}$
HEATUP	4.00 HRS	391	195	2.800	458071	6597135	-50736
	4.25	413	185	2.800	461449	6476416	-51458
	4.35	423	186	2.800	462890	7180705	-51511
	4.47	435	186	3.200	464736	7388687	-45132
	5.00	466	186	3.00	361170	7644238	-26387
STEADY STATE		544	186	0.200	17291	8070624	-309
COOLDOWN	4.00 HRS	253	182	-2.600	-402539	1985035	42947
	4.25	230	181	-2.600	-406478	1579171	43788
	4.35	221	181	-2.700	-408144	1426549	42733
	4.47	209	180	-2.500	-410452	1210175	46750
	5.00	177	180	-2.900	-304752	960719	25801

3. CONTINUITY MATRIX AND LOADING VECTORS:

THE MATRIX FOR THE SOLUTION FOR THE THERMAL LOADINGS WILL BE ARRANGED AS SHOWN BELOW

$$E\Delta_{11} - E\Delta_{21} = E\delta_{21T} - E\delta_{11T}$$
$$E\Delta^*_{11} - E\Delta^*_{21} = E\delta^*_{21T} - E\delta^*_{11T}$$
$$E\Delta_{22} - E\Delta_{12} = E\delta_{12T} - E\delta_{22T}$$
$$E\Delta^*_{22} - E\Delta^*_{12} = E\delta^*_{12T} - E\delta^*_{22T}$$
$$E\Delta_{33} - E\Delta_{43} = E\delta_{43T} - E\delta_{33T}$$
$$E\Delta^*_{33} - E\Delta^*_{43} = E\delta^*_{43T} - E\delta^*_{33T}$$
$$EV_{23} - EV_{33} = EV_{33T} - EV_{23T}$$

THE SOLUTION FOR THE APPLIED LOADS WERE DETERMINED IN THE MECHANICAL ANALYSIS (S-150-P).

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION Fatigue Evaluation Of Head Flange, Vessel Flange And Closure Studs

NUMBER 5-151-P | A 71
SHEET 20 OF 51
DATE 5-12-66 BY Cornell
CHECK DATE 5-12-66 BY Alexander

5. Detailed Analysis

d. Development Of Continuity Equations:

3. Continuity Matrix And Loading Vectors:

Substituting The Deflections And Rotations In The Compatibility Equations As Given On Sheet -19 And Writing In Matrix Form Yields The Following Matrix And Loading Vectors:

$$
\begin{bmatrix}
162.1377 & 2.2709 & 82.6039 & 3.9830 & 0 & 0 & -27.6278 \\
2.2709 & 0.9044 & -5.3262 & -0.3490 & 0 & 0 & 2.5123 \\
-72.3658 & 4.4028 & -2018.0589 & -74.7959 & 207.4870 & 17.9066 & 135.7537 \\
2.4295 & -0.2794 & 24.7459 & 4.9025 & -5.2079 & -0.4052 & -5.1742 \\
0 & 0 & -212.4230 & -5.4911 & 152.4692 & 2.6013 & 39.0249 \\
0 & 0 & -18.8117 & -0.4270 & 2.6013 & 0.2189 & 2.7619 \\
24.1997 & -1.9379 & 165.7558 & 5.1743 & -36.0804 & -2.8105 & -48.1749
\end{bmatrix}
\begin{bmatrix} H_1 \\ M_1 \\ H_2 \\ M_2 \\ H_3 \\ M_3 \\ V \end{bmatrix}
$$

Steady State

Heatup

T=400	T=425	T=435	T=457	T=500
-2212,270	-2296,590	-2331,160	-2367,380	-2105,180
-24,352	-234,790	-234,050	-233,770	-165,500
1933,219	4326,047	4835,205	5267,341	5313,263
-44,989	-56,284	-66,435	-76,072	-158,163
4513,598	4712,647	4916,004	5034,757	5494,714
31,550	92,860	103,220	119,630	199,170
-1112,242	-1304,099	-1391,680	-1481,383	-2079,022

$$
\begin{bmatrix} -12,000 \\ -4,810 \\ 5097,179 \\ -121,723 \\ 1752,849 \\ 125,750 \\ -366,841 \end{bmatrix}
$$

Cooldown

T=400	T=425	T=435	T=457	T=500
2096,790	2137,860	2167,270	2181,990	1958,810
195,340	197,030	196,920	196,960	134,550
-109,310	-1292,952	-1589,907	-1849,120	-4630,996
-26,902	-13,648	-7,340	-908	72,637
-3041,073	-3314,153	-3996,461	-3538,587	-3863,384
-3,210	-16,350	-24,010	-24,970	-101,400
671,377	820,286	980,239	953,544	1478,570

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION: FATIGUE EVALUATION OF HEAD FLANGE, VESSEL FLANGE AND CLOSURE STUDS

NUMBER S-151-P | A72
SHEET 21 OF 51
DATE 5-12-66 BY COCKRELL
CHECK DATE 5-12-66 BY ALEXANDER

5. DETAILED ANALYSIS:

d. DEVELOPMENT OF CONTINUITY EQUATIONS:

4. REDUNDANT LOAD VALUES:

SOLVING THE MATRIX ON SHEET - 20 WITH THE GIVEN LOADING VECTORS FOR THE HEATUP, STEADYSTATE AND COOLDOWN CONDITIONS, WE GET THE FOLLOWING REDUNDANT FORCES. THE VALUES OF THE REDUNDANT FORCES FOR BOLT-UP, CORE SUPPORT WEIGHT, CORE HOLDDOWN SPRING FORCE AND INTERNAL PRESSURE ARE TAKEN FROM CALCULATION NO. S-150-P. THE VALUES OF THE REDUNDANT FORCES FOR INTERNAL PRESSURE ARE LEFT IN TERMS OF PRESSURE SINCE THE ACTUAL PRESSURE DURING THE TRANSIENT WILL BE USED.

TRANSIENT		H_1	M_1	H_2	M_2	H_3	M_3	V
BOLT-UP ONLY		23.2120	-329.4526	3.3876	-19.1672	-18.2221	-391.0394	—
CORE SUPPORT WEIGHT		-0.0112	0.0771	0.0550	-0.7267	-0.2172	-4.5965	—
CORE HOLDDOWN SPRING		0.2130	-3.0486	0.0426	-0.3261	-0.2134	-4.5652	—
INTERNAL PRESSURE		-0.04134P	-8.38228P	-1.09038P	19.89019P	1.22229P	9.64912P	3.90667P
HEATUP	4.00 HRS	-7.6782	-275.2234	2.6804	-13.3455	28.4550	-3.7709	18.4845
	4.25	-7.7770	-275.9300	2.5753	-10.5385	29.2491	3.6531	19.8155
	4.35	-8.1679	-275.0594	2.5149	-8.9711	30.7851	13.9666	20.0634
	4.47	-9.4331	-273.9405	2.6621	-10.3082	36.7298	41.7267	20.1573
	5.00	-6.8833	-213.1766	2.2308	-4.5564	30.5946	141.8189	24.2974
STEADY STATE		2.5837	-17.3723	-0.1853	-1.7866	8.5167	144.3207	3.8965
COOLDOWN	4.00 HRS	8.0529	224.1142	-2.3640	7.7285	-20.5951	92.0124	-16.1701
	4.25	7.7977	231.9945	-2.4440	7.8418	-21.7476	85.5139	-18.7198
	4.35	7.8722	232.8309	-2.3687	6.2311	-21.9726	77.8335	-19.2652
	4.47	7.5940	237.8749	-2.3461	5.6215	-22.5571	84.3951	-21.0675
	5.00	6.4418	179.6209	-1.8011	-2.0546	-21.7719	-13.7274	-24.0173

UNITS ON FORCES:

FOR H's LBS PER INCH OF CIRCUMFERENCE
M's IN-KIPS PER INCH OF CIRCUMFERENCE
V's LBS PER INCH OF CIRCUMFERENCE

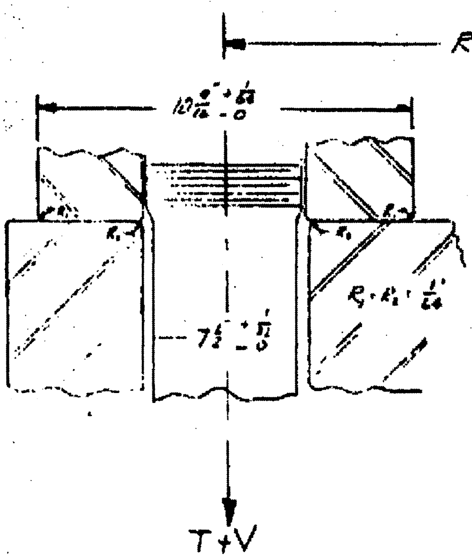
} APPLIED AT THEIR RESPECTIVE RADII.

5. DETAILED ANALYSIS:

e. STRESSES:

1. UNCONCENTRATED:

CONSIDER THE BEARING STRESS BETWEEN THE STUD WASHER AND CLOSURE HEAD. AT THE END OF THE HEATUP TRANSIENT, THE AXIAL LOAD ON THE CLOSURE STUD WILL BE THE GREATEST; HENCE, THE BEARING STRESS BETWEEN THE STUD WASHER AND CLOSURE HEAD WILL BE THE GREATEST. NOTE THAT THE CHANGE IN BOLT LOAD, OVER THE INITIAL COLD BOLT-UP LOAD, IS APPROXIMATELY 28 % TOTAL FOR BOTH PRESSURE AND THERMAL EFFECTS.



LOAD PER STUD $= \frac{2\pi R_B(T+V)}{54}$ [SEE SHEET 23 FOR VALUES OF T & V]

$= \left[\frac{116.532 + 3.9 [illegible] - 4.[illegible]}{54}\right] 2\pi R_B$

$= 1670.2$ KIPS.

MINIMUM O.D. OF WASHER:

$10.5625 - 0.0313 = 10.5312''$

MAXIMUM DIA. OF STUD HOLE:

$7.500 + 0.0625 = 7.5625''$

BEARING AREA PER STUD $= \frac{\pi}{4}\left[\overline{10.5312}^2 - \overline{7.5625}^2\right] = 42.19\ in^2$

$\sigma_B = \frac{T+V}{A_B} = \frac{1670.2}{42.19} = \underline{39.6\ ksi}$

ALLOWABLES: SEE CRITERION 5-C-1	FLANGE: $1.5 S_m = 40$ ksi WASHER: $1.5 S_m = 59.2$ ksi BOTH AT 350°F (ACTUAL TEMP)

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

NUMBER 5-151-D | A 74
SHEET 23 OF 51
DATE 5-12-66 BY CRICKRELL
CHECK DATE 5-12-66 BY ALEVALDOR

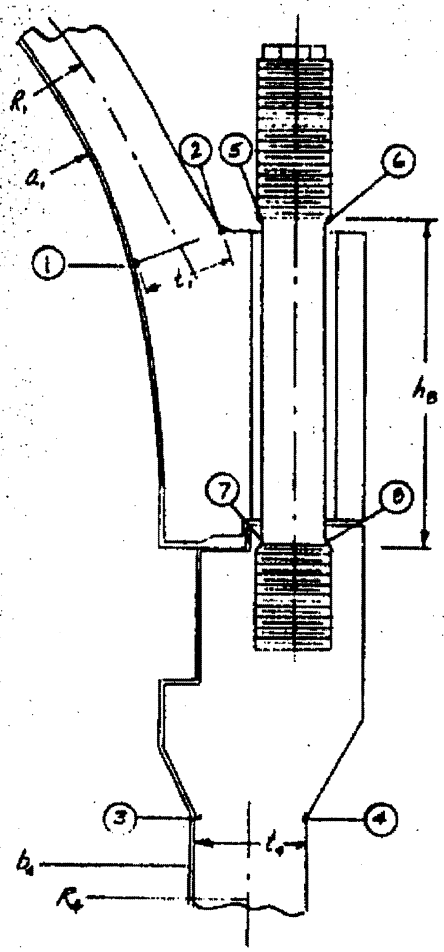
DESCRIPTION FATIGUE EVALUATION OF HEAD FLANGE, VESSEL FLANGE AND CLOSURE HEAD

5. DETAILED ANALYSIS:

e. STRESSES:

1. UNCONCENTRATED:

STRESSES WILL BE CALCULATED AT THE LOCATIONS AS SHOWN BELOW.



POINTS 1 & 2:

$$\sigma_x = \pm \frac{b_1}{t_1^2}(M_1 + M_{T1}) + \frac{H_1 \cos\theta}{t_1} + \frac{a_1 P}{2R_1 t_1} + \frac{E\alpha}{(1-\nu)}(T_{m1} - T)$$

$$= \pm 0.06783(M_1 + M_{T1}) + 0.03654 H_1 + 4.3709 P + 1.42857 E\alpha (T_{m1} - T)$$

$$\sigma_\theta = \pm \frac{\nu b_1}{t_1^2}(M_1 + M_{T1}) + \frac{\nu H_1 \cos\theta}{t_1} + \frac{E\Delta_{11} + E\delta_{11T}}{R_1 \sin\theta} + \frac{t_1 \cos\theta (E\Delta_{11}^{\alpha} + E\delta_{11T}^{\alpha})}{2R_1 \sin\theta} + \frac{a_1 P}{2R_1 t_1} + \frac{E\alpha (T_{m1} - T)}{(1-\nu)} - E\alpha (T_{m1} - 70) = \pm 1.02035 (M_1 + M_{T1}) + 0.01096 H_1 + 0.01189 (E\Delta_{11} + E\delta_{11T}) \pm 0.01122 (E\Delta_{11}^{\alpha} + E\delta_{11T}^{\alpha}) + 4.3709 P + 1.42857 E\alpha (T_{m1} - T) - E\alpha (T_{m1} - 70)$$

POINTS 3 & 4:

$$\sigma_x = \pm \frac{b_4}{t_4^2}(M_3 + M_{T3}) + \frac{b_4 P}{2R_4 t_4} + \frac{E\alpha}{(1-\nu)}(T_{m4} - T)$$

$$= \pm 0.05191 (M_3 + M_{T3}) + 3.7296 P + 1.42857 E\alpha (T_{m4} - T)$$

$$\sigma_\theta = \pm \frac{\nu b_4}{t_4^2}(M_3 + M_{T3}) + \frac{E M_{T3}}{2R_4 \beta_4^2 D_4} + \frac{E\Delta_{43}}{R_4} + \frac{b_4 P}{t_4} + \frac{E\Delta_4}{(1-\nu)}(T_{m4} - T) = \pm 0.01557 (M_3 + M_{T3}) + 0.02880 M_{T3} + 0.01098 E\Delta_{43} + 7.94762 P + 1.42857 E\alpha (T_{m4} - T)$$

POINTS 5 & 6:

$$\sigma_y = \frac{T + \bar{V}}{A} \pm \frac{\bar{M} c}{I} = 0.31631 (T + \bar{V}) \pm 0.36236 M_2$$

POINTS 7 & 8:

$$\sigma_z = \frac{T + \bar{V}}{A} \pm \frac{(\bar{M} + \bar{H} R_8) c}{I} = 0.31631 (T + \bar{V}) \pm 0.36236 M_2 \pm 11.33489 H_2$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT. CHATTANOOGA. TENN.
CHARGE NO.

NUMBER 5-151-P | A 75
SHEET 24 OF 51
DATE 5-12-66 BY COCKRELL
CHECK DATE 5-12-66 BY ALEXANDER

DESCRIPTION FATIGUE EVALUATION OF HEAD FLANGE, VESSEL FLANGE AND CLOSURE STUDS

5. DETAILED ANALYSIS:

e - STRESSES:

1. UNCONCENTRATED:

THE FOLLOWING TABLES GIVE THE MECHANICAL AND THERMAL STRESSES, THE TOTAL STRESS, AND STRESS INTENSITIES AT THE LOCATIONS AS SHOWN ON SHEET-23. STRESSES FOR THE MECHANICAL LOADS AND FOR THE HEATUP AND COOLDOWN CYCLES WERE CALCULATED BY USING THE STRESS EXPRESSIONS AS GIVEN ON SHEET-23 AND THE VALUES OF THE REDUNDANT FORCES LISTED ON SHEET-21. THERMAL STRESSES FOR ALL OTHER TRANSIENT CONDITIONS WERE CONSERVATIVELY CALCULATED BY TREATING THE CHANGE IN REACTOR COOLANT TEMPERATURE AS A STEP EFFECT ON THE INSIDE SURFACE OF THE VESSEL. THIS METHOD WAS USED SINCE THE MEAN TEMPERATURE OF THE VESSEL WALL WILL NOT DEVIATE APPRECIABLY FROM THE MEAN TEMPERATURE EXISTING AT STEADY STATE AND BECAUSE THE TRANSIENTS ARE OF SHORT DURATION. THE STRESS AT THE INSIDE SURFACE WILL BE CALCULATED ASSUMING THAT THE SURFACE WILL BE AT A TEMPERATURE EQUAL TO THE REACTOR COOLANT TEMPERATURE AND IS CALCULATED FROM THE EXPRESSION:

$$\sigma_x = \sigma_\theta = \frac{E\alpha}{1-\nu}(T_m - T)$$

WHERE,

T = REACTOR COOLANT TEMPERATURE

T_m = MEAN TEMP. OF VESSEL WALL AT LOCATION OF INTEREST

$E\alpha$ = YOUNG'S MODULUS TIMES COEFFICIENT OF THERMAL EXPANSION

ν = POISSON'S RATIO

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. _____

DESCRIPTION Fatigue Evaluation of Head Flange Vessel Flange and Closure Studs

NUMBER S-151-P | A76
SHEET 85 OF 51
DATE 5-12-66 BY Caldwell
CHECK DATE 5-12-66 BY Alexander

5-Detailed Analysis:
e-Stresses:
1-Uncircumferential:

Location 1

Transient	Internal Pressure psig	$(T_{avg}-T)$ °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	Stress Intensity $\sigma_\theta-\sigma_r$	Stress Intensity $\sigma_x-\sigma_r$
Zero Stress	0	0	0	0	-2.150	-2.51	0	-2.150	-2.51	0	-18.99	-2.150	-2.51
Full Pressure 2485 psig	2.5	0	0	0	-11.99	6.17	-2.50	-1.199	6.17	-2.50	-18.16	-9.49	-2.67
a 4 hrs	1.832		-17.50	-26.63	-19.25	4.92	-1.82	-21.35	-22.41	-1.93	-9.24	-29.17	-29.73
1.25	2.078		-19.50	-27.91	-18.60	4.70	-2.08	-31.95	-23.29	-2.08	-9.70	-29.90	-21.20
4.35	2.856		-18.57	-28.19	-18.31	4.97	-2.16	-31.69	-23.22	-2.16	-9.76	-29.52	-21.06
4.97	2.250		-18.61	-28.73	-12.95	5.30	-2.25	-21.56	-23.43	-2.25	-9.13	-29.31	-21.18
5.00	2.250		-13.80	-22.43	-12.95	5.30	-2.25	-26.75	-17.13	-2.25	-9.62	-24.50	-14.88
Steam Spike	2.250		-1.23	-0.59	-12.95	5.30	-2.25	-14.18	4.71	-2.25	-18.89	-11.93	6.96
b 100 hrs	0.315		14.96	24.85	-20.30	-1.42	-0.32	-5.34	23.43	-0.32	-29.77	-5.02	23.75
4.15			16.29	25.49				-4.01	24.07	-0.32	-28.09	-3.69	24.39
4.35			16.83	25.74				-3.67	24.32	-0.32	-28.19	-3.55	24.64
4.97			16.80	25.89				-3.50	24.47	-0.32	-27.97	-3.18	24.79
500			11.69	19.46				-9.61	18.24	-0.32	-26.85	-9.29	18.56
c 20 min	2.250	-78	-3.63	-2.99	-12.95	5.30	-2.25	-16.58	2.31	-2.25	-18.89	-14.33	4.56
d 20 min	2.250	28	1.17	1.91	-12.95	5.30	-2.26	-11.78	7.11	-2.25	18.89	-9.53	2.36
e 80 sec	2.110	11.2	2.21	2.95	-13.57	4.92	-2.14	-11.16	7.77	-2.14	-11.93	-9.02	9.91
225 sec	2.275	1.7	-0.71	-0.07	-12.85	5.38	-2.28	-13.56	5.31	-2.29	-18.87	-11.28	7.59

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT. CHATTANOOGA, TENN.

NUMBER S-151-P | A 77
SHEET 26 OF 51
CHARGE NO.
DATE 5-12-66 BY
DESCRIPTION Fatigue Evaluation Of Head Flange & Vessel Flange And Closure Studs
CHECK DATE 5-12-66 BY

5. Detailed Analysis:
e - Stresses:
1. Unpowered Cated:

Location - 1

Transient		Design Pressure psia	$(T_m - T)$ °F	Thermal Stress			Pressure Stress			Total Stress			Stress Intensity		
				T_t	T_o	T_r	T_t	T_o	T_r	T_t	T_o	T_r	$T_t - T_o$	$T_o - T_r$	$T_t - T_r$
f	40sec	2320	-9.3	-9.19	-3.45	-2.32	-12.69	5.54	-2.32	-16.77	2.09	-2.32	-18.86	-14.45	3.41
	100sec	2260	-13.3	-5.31	-4.47	-2.26	-12.91	5.33	-2.26	-18.22	0.66	-2.26	-18.88	-15.96	2.92
	280sec	2160	-1.3	-1.63	-0.99	-2.14	-13.37	4.92	-2.14	-15.00	3.93	-2.14	-18.93	-12.86	6.07
g	2 min	2370	-12.0	-4.92	-4.28	-2.37	-12.49	5.71	-2.37	-17.41	1.43	-2.37	-18.84	-15.04	3.80
	3.1 min	2350	-15.0	-5.84	-5.20	-2.35	-12.67	5.64	-2.35	-18.41	0.44	-2.35	-18.85	-16.06	2.79
	Mfpd	2150	0	-1.23	-0.59	-2.15	-13.33	4.95	-2.15	-14.56	4.36	-2.15	-16.92	-12.41	6.51
h	10 sec	2320	-9.5	-4.15	-3.51	-2.22	-13.06	5.19	-2.22	-17.21	1.68	-2.22	-18.99	-14.99	3.90
	65sec	1910	8.5	1.38	2.32	-1.91	-14.24	4.12	-1.91	-12.86	6.14	-1.91	-19.00	-10.95	8.05
i	220 min	3125	0	0	0	-2.62	-9.62	8.33	-3.13	-9.62	8.33	-3.13	-17.95	-6.49	11.46
j	Heatup 35 hrs	1250		-28.73	-19.41		-16.75	1.93	-1.25	-35.34	-26.90	-1.25	-9.46	-34.11	-25.65
	S.S. (assumed 35 hrs)	2500		-0.59	-1.23		-11.99	6.17	-2.50	-13.22	5.58	-2.50	-18.80	-18.72	0.08
		0.315		25.99	16.80		-20.30	-1.42	-0.32	-3.50	24.47	-0.32	-27.97	-3.18	24.79
k	~	2350	6.0	1.25	3.61	-2.57	-12.57	5.64	-2.35	-11.96	6.69	-2.35	-18.85	-9.16	9.24
	~	1.50	-6.0	-2.43	-3.07	-2.15	-13.33	4.95	-2.15	-16.40	2.52	-2.15	-18.92	-14.25	4.64
l	12sec	2.250	33.3	9.66	9.00	-2.25	-12.95	5.30	-2.25	-3.95	14.96	-2.25	-18.99	-1.70	17.19
m	10 sec	2.760	-30.2	-9.87	-10.51	-2.76	-11.01	7.07	-2.76	-21.52	-2.96	-2.76	-18.72	-18.76	-0.04
	25 sec	2.170	-41.2	-13.34	-13.82	-2.12	-13.44	4.55	-2.12	-27.32	-9.39	-2.12	-18.93	-25.20	-6.27
	140 sec	1.440	4.9	0.66	0.24	-1.44	-16.03	2.69	-1.44	-15.79	3.37	-1.44	-19.16	-14.35	+4.81
n	35 sec	1.300	117	35.55	34.71	-0.30	-20.36	-1.47	-0.30	14.35	33.66	-0.30	-19.53	14.65	34.18
	54 sec	0.760	197	59.92	59.28	-0.70	-18.84	-0.08	-0.70	40.44	59.94	-0.70	-19.40	41.14	60.54

$S.I._{MAX} = (\sigma_o - \sigma_r) = 50.40 ksi < 3S_m = 80.1 ksi$ Criterion 5-2-2
Range

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-151-P | A 7B
SHEET 27 OF 51
CHARGE NO.
DATE 5-12-66 BY COCKRELL
DESCRIPTION Fatigue Evaluation of Head Flange, Vessel Flange and Closure Studs
CHECK DATE 5-12-66 BY ALEXANDER

5. Detailed Analysis:

e. Stresses:

1. Unconcentrated:

LOCATION 2

Transient		Internal Pressure ksia	$(T_m - T)$ °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x - \sigma_\theta$	Stress Intensity $\sigma_x - \sigma_r$	Stress Intensity $\sigma_\theta - \sigma_r$
Cold Bolt up		0	0	0	0	23.20	13.74	0	23.20	13.74	0	9.46	23.20	13.74
Bolt up & 2500 psia		2.5	0	0	0	35.56	23.80		35.54	23.80		11.74	35.54	23.80
a Heatup	4.00 hrs	1.832		12.25	8.53	32.49	21.31		44.74	29.84		14.90	44.74	29.84
	4.25	2.078		13.09	9.06	33.46	22.10		46.55	31.16		15.39	46.55	31.16
	4.35	2.156		13.04	9.00	33.85	22.41		46.89	31.41		15.48	46.89	31.41
	4.47	2.250		13.54	7.20	34.31	22.79		47.85	29.99		17.86	47.85	29.99
	5.00	2.250		10.91	6.72	34.31	22.79		45.22	29.51		15.71	45.22	29.51
Steady State		2.250		0.99	0.29	34.31	22.79		35.30	23.08		12.22	35.30	23.08
b Cooldown	4.00 hrs	0.315		-9.74	-6.60	24.76	15.01		15.02	8.41		6.61	15.02	8.41
	4.25	↓		-10.83	-7.35	↓	↓		13.93	7.66		6.27	13.93	7.66
	4.35	↓		-10.45	-6.89	↓	↓		14.31	8.12		6.19	14.31	8.12
	4.47	↓		-10.87	-7.23	↓	↓		13.89	7.78		6.11	13.89	7.78
	5.00	↓		-9.36	-5.71	↓	↓		15.40	9.30		6.10	15.40	9.30
c	20 min	2.250	0	0.99	0.29	34.31	22.79		35.30	23.08		12.22	35.30	23.08
d	20 min	2.250	↓	↓	↓	34.31	22.79		35.30	23.08		12.22	35.30	23.08
e	100 sec	2.110	↓	↓	↓	33.77	22.35		34.76	22.64		12.12	34.76	22.64
	225 sec	2.275	↓	↓	↓	34.43	22.89	↓	35.42	23.18	↓	12.24	35.42	23.18

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-151-P 1A-79
SHEET 28 OF 51
CHARGE NO.
DATE 5-12-66 BY
DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs
CHECK DATE 5-12-66 BY

5. Detailed Analysis:

a. Stresses:

1. Unconcentrated:

Location - 2

	Transient	Internal Pressure psia	$(T_o - T)$ °F	Thermal Stress P_r	Thermal Stress P_o	Pressure Stress P_r	Pressure Stress P_o	Pressure Stress P_r	Total Stress P_r	Total Stress P_o	Total Stress P_r	Stress Intensity $P_o - P_r$	Stress Intensity $P_r - P_r$	Stress Intensity $P_o - P_r$
f	40 sec	2.320	0	0.99	0.29	34.66	22.07	0	35.65	23.36	0	12.29	35.65	23.36
	130 sec	2.260				34.56	22.83		35.55	23.12		12.23	35.55	23.12
	260 sec	2.140				33.77	22.35		34.76	22.64		12.12	34.76	22.64
g	2 min	2.370				34.90	23.29		35.99	23.57		12.32	35.89	23.57
	3.2 min	2.350				34.86	23.19		35.79	23.48		12.31	35.79	23.48
	4.4 min	2.150				33.82	22.39		34.81	22.68		12.13	34.81	22.68
h	10 sec	2.220				34.16	22.07		35.15	22.96		12.19	35.15	22.96
	65 sec	1.910				32.63	21.42		33.62	21.71		11.91	33.62	21.71
c'	220 min	3.125		0	0	39.63	26.31		38.63	26.31		12.32	38.63	26.31
j	Max. 35 ksi/s	1.250		13.54	7.20	29.37	19.77		42.91	25.97		16.94	42.91	25.97
	S.S. (assumed 25 ksi/s)	2.500		0.99	0.29	35.54	23.80		36.53	24.09		12.44	36.53	24.09
		0.315		-10.87	-7.23	24.76	15.01		13.89	7.78		6.11	13.89	7.78
l	~	2.360	0	0.99	0.29	34.80	23.19		35.79	23.48		12.31	35.79	23.48
	~	2.050				33.82	22.39		34.81	22.68		12.13	34.81	22.69
l	12 sec	2.230				34.31	22.79		35.30	23.08		12.22	35.30	23.08
m	10 sec	2.760				36.83	24.84		37.82	25.13		12.69	37.82	25.13
	25 sec	2.170				33.67	22.27		34.66	22.56		12.10	34.66	22.56
	110 sec	1.490				30.31	19.53		31.30	19.82		11.48	31.30	19.62
n	33 sec	4.300				24.68	14.95		25.67	15.24		10.43	25.67	15.24
	54 sec	0.700				26.66	16.56		27.65	16.85		10.90	27.65	16.85

$SI_{max} = (\sigma_x - \sigma_r) = 47.85\ ksi < 3S_m = 90.1\ ksi$ (Criteria 5-C-2)

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-151-P 1A00
SHEET 29 OF 51
DATE 5-12-66 BY Ackerman
CHECK DATE 5-12-66 BY Alexander
CHARGE NO. ____
DESCRIPTION Fatigue Evaluation of Head Flange, Vessel Flange and Closure Studs

5. Detailed Analysis:

e. Stresses:

1- Unconcentrated:

Location 3

Transient		Internal Pressure ksia	(T_m-T) °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	Stress Intensity $\sigma_x-\sigma_r$	Stress Intensity $\sigma_\theta-\sigma_r$
Cold Bolt Up		0	0	0	0	-20.30	-4.59	0	-20.30	-4.59	0	-15.71	-20.30	4.59
Bolt up & 2500 psia		2.5	0	0	0	-9.72	14.22	-2.50	-9.72	4.22	-2.50	-23.94	-7.22	16.72
a Heatup	4.00 hrs.	1.892		-3.10	-26.29	-12.24	9.57	-1.19	-15.44	-16.72	-1.19	1.39	-14.25	-15.53
	4.25	2.078		-3.09	-27.00	-11.51	11.04	-2.08	-14.60	-15.96	-2.08	1.36	-12.52	-13.39
	4.35	2.156		-2.61	-27.35	-11.18	11.63	-2.16	-13.79	-15.72	-2.16	1.93	-11.63	-13.56
	4.47	2.250		-1.67	-26.94	-10.78	12.34	-2.25	-12.45	-14.60	-2.25	2.15	-10.20	-12.35
	5.00	2.250		5.31	-19.85	-10.78	12.34	-2.25	-5.47	-7.51	-2.25	2.04	-3.22	-5.26
Steady State		2.250		7.48	5.30	-10.78	12.34	-2.25	-3.30	12.64	-2.25	-15.94	-1.05	14.89
b Cooldown	4.00 hrs.	0.315		9.42	25.13	-19.97	-2.22	-0.32	-10.55	22.91	-0.32	-33.46	-10.23	23.23
	4.25	↓		7.90	25.49	↓	↓	↓	-11.07	23.27	-0.32	-34.34	-10.75	23.59
	4.36	↓		7.55	25.38	↓	↓	↓	-11.42	23.16	-0.32	-34.58	-11.10	23.48
	4.47	↓		9.18	26.38	↓	↓	↓	-10.79	24.16	-0.32	-34.95	-10.47	24.48
	5.00	↓		1.27	18.87	↓	↓	↓	-17.70	16.65	-0.32	-34.35	-17.38	16.97
c	20 min	2.250	-7.8	5.08	-2.10	-10.78	12.34	-2.25	-5.70	10.24	-2.25	-15.94	-3.45	12.49
d	20 min	2.250	7.8	9.88	2.70	-10.78	12.34	-2.25	-0.90	15.04	-2.25	-15.94	1.35	17.29
e	100 sec	2.110	11.2	10.92	3.74	-11.25	11.51	-2.14	-0.33	15.25	-2.14	-15.58	1.91	17.39
	225 sec	2.275	1.7	8.00	0.92	-10.68	12.53	-2.28	-2.68	13.35	-2.28	-16.03	-0.40	15.63

COMBUSTION ENGINEERING, INC. NUMBER 5-1512 | A 81
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN. SHEET 30 OF 51
CHARGE NO. _____ DATE 5-12-66 BY [illegible]
DESCRIPTION Fatigue Evaluation Of Head Flange CHECK DATE 5-12-66 BY [illegible]
Vessel Flange And Closure Studs

5. Design Analysis:

C. Stresses:

1. Unconcentrated:

LOCATION - 3

Transient		Internal Pressure PSIA	$(T_m - T)$ °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x - \sigma_\theta$	Stress Intensity $\sigma_x - \sigma_r$	Stress Intensity $\sigma_\theta - \sigma_r$
f	40 sec	2.320	-9.3	4.62	-2.56	-10.49	12.97	-2.32	-5.87	10.31	-2.32	-16.18	-3.55	12.63
	100 sec	2.260	-13.3	3.40	-2.78	-10.74	12.41	-2.26	-7.34	9.63	-2.26	-15.97	-5.08	10.89
	260 sec	2.140	-1.3	7.08	-0.10	-11.25	11.51	-2.14	-4.17	11.41	-2.14	-15.58	-2.03	13.55
g	.2 min	2.370	-12.0	3.79	-3.39	-10.27	13.24	-2.37	-6.48	9.85	-2.37	-16.33	-4.11	12.22
	3.2 min	2.350	-15.0	2.97	-4.31	-10.36	13.09	-2.35	-7.49	8.78	-2.35	-16.27	-5.14	11.13
	10.4 min	2.150	0	7.48	0.30	-11.20	11.59	-2.15	-3.72	11.89	-2.15	-15.61	-1.57	14.04
h	10 sec	2.220	-9.5	4.56	-2.62	-10.91	12.11	-2.22	-6.35	9.49	-2.22	-15.84	-4.13	11.71
	65 sec	1.910	9.5	10.09	2.91	-12.22	9.78	-1.91	-2.13	12.69	-1.91	-14.82	-0.22	14.60
i	220 min	3.125	0	0	0	-7.08	18.92	-3.13	-7.08	18.92	-3.13	-26.00	-3.95	22.05
j	Heatup 25 hrs	1.250	X	-1.67	-26.94	-15.01	4.92	-1.25	-16.68	-22.12	-1.25	5.44	-15.43	-20.87
	S.S.	2.500	X	7.98	0.30	-9.72	14.22	-2.50	-2.24	14.52	-2.50	-16.76	0.26	17.02
	Cooldown 35 hrs	0.315	X	9.18	26.38	-18.97	-2.22	-0.32	-10.79	24.16	-0.32	-34.95	-10.47	24.48
k	~	2.350	6.0	9.32	2.14	-10.36	13.09	-2.35	-1.04	15.23	-2.35	-16.27	1.31	17.58
	~	2.150	-6.0	5.64	-1.54	-11.20	11.59	-2.15	-5.56	10.05	-2.15	-15.61	-3.41	12.20
l	12 sec	2.350	33.3	17.71	10.53	-10.78	12.34	-2.25	6.93	22.87	-2.25	-15.94	9.18	25.12
m	10 sec	2.760	-30.2	-1.80	-9.98	-8.62	16.18	-2.76	-10.42	7.20	-2.76	-17.62	-7.66	9.96
	29 sec	2.110	-41.2	-5.17	-12.35	-11.33	11.36	-2.12	-16.50	-0.99	-2.12	-15.51	-14.39	1.13
	160 sec	1.490	4.8	8.95	1.77	-14.21	6.24	-1.44	-5.26	3.01	-1.44	-13.27	-3.92	9.45
n	33 sec	0.300	117	43.42	36.24	-19.03	-2.33	-0.30	24.39	33.91	-0.30	-9.52	24.69	34.21
	54 sec	0.700	197	67.79	60.81	-17.34	0.68	-0.70	50.65	61.49	-0.70	-10.84	51.35	62.19

$S.I._{\text{MAX RANGE}} = (\sigma_\theta - \sigma_r) = 45.35\ Ksi < 50.1\ Ksi$ CRITERIA 5-C-2

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ________

DESCRIPTION Fatigue Evaluation of Head Flange, Vessel Flange and Closure Studs

NUMBER 5-151-P | A 82
SHEET 31 OF 51
DATE 5-12-66 BY Cockrell
CHECK DATE 5-12-66 BY Alexander

5- Detailed Analysis:
e: Stresses:
1- Unconcentrated:

Location 4

Transient		Internal Pressure ksia	$(T_m - T)$ °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x - \sigma_\theta$	Stress Intensity $\sigma_x - \sigma_r$	Stress Intensity $\sigma_\theta - \sigma_r$
Cold Bolt up		0	0	0	0	20.30	7.59	0	20.30	7.59	0	12.71	20.30	7.59
Bolt up + 2500 psia		2.5	0	0	0	28.37	25.65	↓	28.37	25.65	↓	2.72	28.37	25.65
a Heatup	4.00 hrs	1.882		-7.92	1.91	26.38	21.19		18.46	22.99		-4.53	18.46	22.99
	4.25	2.078		-9.04	1.86	27.01	22.60		18.97	24.46		-5.49	18.97	24.46
	4.35	2.156		-9.27	1.65	27.26	23.16		18.99	24.91		-5.32	18.99	24.91
	4.47	2.250		-9.52	2.02	27.56	23.84		19.04	25.86		-7.92	19.04	25.86
	5.00	2.250		-13.04	-1.64	27.56	23.84		14.52	22.20		-7.69	14.52	22.20
Steady State		2.250		-7.78	-3.21	27.56	23.84		19.78	20.63		-0.85	19.79	20.63
b Cooldown	4.00 hrs	0.315		1.78	-4.08	21.32	9.87		23.10	5.79		17.31	23.10	5.79
	4.25	↓		1.93	-2.81	↓	↓		23.25	6.06		17.19	23.25	6.06
	4.35			2.49	-3.70				23.91	6.17		17.64	23.91	6.17
	4.47			2.62	-2.59				23.94	6.98		16.96	23.94	6.98
	5.00			5.37	-0.18				26.69	9.69		17.00	26.69	9.69
c	20 min	2.250	0	-7.78	-3.21	27.56	23.84		19.78	20.63		-0.85	19.78	20.63
d	20 min	2.250	↓	↓	↓	27.56	23.84		19.78	20.63		-0.85	19.78	20.63
e	100 sec	2.110				27.21	22.05		19.43	19.84		-0.41	19.43	19.84
	225 sec	2.275				27.65	24.02	↓	19.87	20.81	↓	-0.94	19.87	20.81

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs

NUMBER 5-151-P | A 83
SHEET 32 OF 51
DATE 5-12-66 BY [illegible]
CHECK DATE 5-12-66 BY Alexander

5. Detailed Analysis:

e - Stresses:

1. Unconcentrated:

Location - 4

Transient		Internal Pressure ksi	$(T_m - T)$ °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	Stress Intensity $\sigma_x-\sigma_r$	Stress Intensity $\sigma_\theta-\sigma_r$
f	40 sec	2.320	0	-7.78	-3.21	27.79	24.35	0	20.01	21.14	0	-1.13	20.01	21.14
	100 sec	2.260				27.60	23.92		19.92	20.71		-0.79	19.92	20.71
	260 sec	2.140				27.21	23.05		19.43	19.84		-0.41	19.43	19.84
g	2 min	2.370				27.95	24.71		20.17	21.50		-1.33	20.17	21.50
	3.2 min	2.350				27.89	24.57		20.11	21.36		-1.25	20.11	21.36
	10.4 min	2.150				27.24	23.12		19.46	19.91		-0.45	19.46	19.91
h	10 sec	2.220				27.47	23.63		19.69	20.42		-0.73	19.69	20.42
	65 sec	1.910				26.47	21.39		18.69	18.18		0.51	18.69	18.18
i	220 min	3.125		0	0	30.39	30.16		30.39	30.16		0.23	30.39	30.16
j	Heating 3.5 hrs	1.250	X	-9.52	2.02	24.34	16.62		14.82	18.64		-3.82	14.82	18.64
	S.S.	2.500		-7.78	-3.21	28.37	25.65		20.59	22.44		-1.85	20.59	22.44
	Cooldown 3.5 hrs	0.315		2.62	-2.99	21.32	9.97		23.94	6.98		16.96	23.94	6.98
k	~	2.350	0	-7.78	-3.21	27.89	24.57		20.11	21.36		-1.25	20.11	21.36
	~	2.150				27.28	23.12		19.46	19.91		-0.45	19.46	19.91
l	12 sec	2.250	"			27.56	23.84		19.78	20.63		-0.85	19.78	20.63
m	16 sec	2.760				29.21	27.53		21.43	24.32		-2.89	21.43	24.32
	25 sec	2.170				27.14	22.90		19.36	19.69		-0.33	19.36	19.69
	160 sec	1.440				24.95	19.99		17.17	16.78		0.39	17.17	16.78
n	33 sec	0.300				21.27	9.76		13.49	6.55		6.94	13.49	6.55
	54 sec	0.700				22.56	12.65		14.78	9.44		5.34	14.78	9.44

$S.I._{max\ range} = \sigma_x - \sigma_r = 30.39$ ksi < 80.1 ksi   Criteria 5-C-2

RIV000053D

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

DESCRIPTION Fatigue Evaluation Of Head Flange, Vessel Flange And Closure Studs

NUMBER 5-151-P | A 04
SHEET 98 OF 51
DATE 5-12-66 BY Cockrell
CHECK DATE 5-12-66 BY [illegible]

5-DETAILED ANALYSIS:

C. STRESSES:

1- UNCONCENTRATED:

Transient		Internal Pressure KSIA	Location-5 Mechanical Stress σ_x	Location-5 Thermal Stress σ_x	Location-5 Total Stress σ_x	Location-6 Mechanical Stress σ_x	Location-6 Thermal Stress σ_x	Location-6 Total Stress σ_x	Location-7 Mechanical Stress σ_x	Location-7 Thermal Stress σ_x	Location-7 Total Stress σ_x	Location-8 Mechanical Stress σ_x	Location-8 Thermal Stress σ_x	Location-8 Total Stress σ_x
Cold Start Up		0	29.91	0	29.91	43.31	0	43.31	68.31	0	68.31	5.41	0	5.41
Heat Up + 2500 psi		2500	53.29	0	53.29	29.61	0	29.61	57.80	0	57.80	22.10	0	22.10
a	4.00 hrs	1.882	45.25	1.01	46.26	34.12	10.63	44.30	60.40	31.39	91.79	17.97	-19.70	-1.73
	4.25	2.078	46.95	2.45	49.30	32.03	10.39	42.09	59.57	31.64	91.21	19.28	-19.10	0.18
	4.35	2.156	47.49	3.10	50.59	31.56	9.60	41.16	59.24	31.61	90.85	19.80	-18.91	0.89
	4.47	2.250	49.25	2.64	50.39	31.03	10.11	41.14	58.95	32.31	91.66	20.43	-20.06	0.37
	5.00	2.250	49.25	6.03	54.28	31.03	9.34	40.37	59.65	31.32	90.17	20.43	-15.95	4.48
Steady State		2.250	49.25	3.59	48.84	31.03	1.88	32.91	58.95	-1.51	57.34	20.43	3.98	24.41
b	4.00 hrs	0.215	32.48	-2.31	30.17	42.02	-7.41	34.11	66.99	-29.11	37.88	7.54	18.89	26.43
	4.25	↓	↓	-3.08	29.40	↓	-9.77	33.25	↓	-30.78	36.21	↓	13.93	26.47
	4.35	↓	↓	-3.83	28.65	↓	-3.35	33.67	↓	-30.68	36.31	↓	13.50	26.04
	4.47	↓	↓	-4.63	27.85	↓	-9.70	33.32	↓	-31.22	35.77	↓	17.89	25.43
	5.00	↓	↓	-9.34	24.14	↓	-6.95	35.17	↓	-29.76	38.23	↓	13.57	21.11
c	20 min	2.250	48.25	0.59	48.84	31.03	1.88	32.91	59.95	-1.51	57.34	20.43	3.98	24.41
d	20 min	2.250	48.25	↓	48.84	31.03	↓	32.91	59.85	↓	57.34	20.43	↓	24.41
e	100 sec	2.140	47.36	↓	47.95	31.65	↓	33.53	59.31	↓	57.80	19.70	↓	23.69
	225 sec	2.275	48.46	↓	49.05	30.88	↓	32.76	58.74	↓	57.23	20.60	↓	24.59

DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs

5. Detailed Analysis:

e. Stresses:

1. Unconcentrated:

Transient		Internal Pressure ksia	Location-5 Mechanical Stress σ	Location-5 Thermal Stress σ	Location-5 Total Stress σ	Location-6 Mechanical Stress σ	Location-6 Thermal Stress σ	Location-6 Total Stress σ	Location-7 Mechanical Stress σ	Location-7 Thermal Stress σ	Location-7 Total Stress σ	Location-8 Mechanical Stress σ	Location-8 Thermal Stress σ	Location-8 Total Stress σ
f	60sec	2.320	49.33	0.59	49.42	30.63	1.89	32.51	58.55	-1.51	57.04	20.90	3.98	24.88
	165sec	2.260	49.34		49.93	30.97		32.85	58.81		57.30	20.50		24.48
	260sec	2.180	47.36		47.95	31.65		33.53	59.31		57.80	19.70		23.68
g	2 min	2.370	49.23		49.82	30.34		32.22	58.34		56.83	21.23		25.21
	3.2 min	2.350	49.07		49.66	30.46		32.34	58.43		56.92	21.10		25.08
	13.4 min	2.150	47.44		48.03	31.59		33.47	59.27		57.76	19.76		23.74
h	10 sec	2.220	49.01		48.60	31.20		33.08	58.97		57.46	20.23		24.21
	65 sec	1.910	45.48	↓	46.07	32.96	↓	34.84	60.28	↓	58.77	18.16	↓	22.14
i	220 min	2.125	55.39	0	55.39	26.05	0	26.05	55.17	0	55.17	26.27	0	26.27
j	Heatup 3.5 hrs	1.250	40.10	2.64	42.74	36.70	10.11	46.81	63.06	32.81	15.87	13.76	-20.26	-6.50
	S.S.	2.500	50.29	0.59	50.88	29.61	1.88	31.49	57.80	-1.51	56.29	22.10	3.98	26.08
	Cooldown 3.5 hrs	2.315	32.48	-4.63	27.85	42.02	-9.70	33.32	66.99	-31.22	35.77	7.54	17.89	25.43
k	~	2.350	49.07	0.59	49.66	30.46	1.88	32.34	58.43	-1.51	56.92	21.10	3.98	25.08
	~	2.150	47.44		48.03	31.59		33.47	59.27		57.76	19.76		23.74
l	12sec	2.250	49.25		48.84	31.03		32.91	58.85		57.34	20.43		24.41
m	10sec	2.760	52.41		53.00	28.13		30.01	56.70		55.19	23.84		27.82
	20sec	2.120	47.19		47.78	31.76		33.64	59.40		57.89	19.56		23.54
	160sec	1.440	41.65		42.24	35.63		37.51	62.25		60.74	15.02		19.00
n	33sec	0.300	32.32		32.91	42.10		43.98	67.05		65.54	7.41		11.39
	54sec	0.700	35.62	↓	36.21	39.82	↓	41.70	65.37	↓	63.86	10.08	↓	14.06

$SI_{max} = 95.87$ ks < 110.2 ks. Criteria 5.C-2

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION FATIGUE EVALUATION OF HEAD FLANGE, VESSEL FLANGE AND CLOSURE STUDS

NUMBER 5-51-P | A86
SHEET 35 OF 51
DATE 5-12-66 BY [illegible]
CHECK DATE 5-12-66 BY [illegible]

5. DETAILED ANALYSIS:

a. STRESSES:

2. CONCENTRATED:

FOR THE PURPOSE OF THE FATIGUE ANALYSIS, THE FOLLOWING STRESS EXPRESSIONS WILL BE USED TO CALCULATE PEAK STRESSES AT THE EIGHT LOCATIONS AS SHOWN ON SHEET -23.

POINTS 1 & 2:

$$\sigma_x = \pm \frac{6}{t_1^2}(M_1 + M_{T1})K_B + \frac{H_1 \cos\theta}{t_1} K_T + \frac{a_1^2 P}{2R_1 t_1} K_T + \frac{E\Delta}{(1-\nu)}(T_{m1} - T)K_T$$

$$= \pm 0.06783(M_1 + M_{T1})K_B + 0.03654 H_1 K_T + 4.3709 P K_T + 1.42857(T_{m1} - T)K_T$$

$$\sigma_\theta = \pm \frac{\gamma t_1}{t_1^2}(M_1 + M_{T1})K_B + \nu \frac{H_1 \cos\theta}{t_1} + \frac{E\Delta_{11} + E\delta_{11}}{R_1 \sin\theta} \pm \frac{t_1 \cos\theta (E\Delta_{11}^{\theta} + E\delta_{11}^{\theta})}{2R_1 \sin\theta} + \frac{a_1^2 P}{2R_1 t_1} + \frac{E\Delta}{(1-\nu)}(T_{m1} - T) - E\Delta(T_{m1} - 70)$$

$$= \pm 0.02035(M_1 + M_{T1})K_B + 0.01096 H_1 + 0.01189(E\Delta_{11} + E\delta_{11}) \pm 0.01922(E\Delta_{11}^{\theta} + E\delta_{11}^{\theta}) + 4.3709 P + 1.42857(T_{m1} - T) - E\Delta(T_{m1} - 70)$$

POINTS 3 & 4:

$$\sigma_x = \pm \frac{6}{t_3^2}(M_3 + M_{T3})K_B + \frac{b^2 P}{2R_4 t_4} K_T + \frac{E\Delta}{(1-\nu)}(T_{m4} - T)K_T$$

$$= \pm 0.05491(M_3 + M_{T3})K_B + 3.7296 P K_T + 1.42857(T_{m4} - T)K_T$$

$$\sigma_\theta = \pm \frac{\gamma t_3}{t_3^2}(M_3 + M_{T3})K_B + \frac{E M_{T3}}{2R_4 P_4^2 \Omega_4} + \frac{E\Delta_{43}}{R_4} + \frac{bP}{t_4} + \frac{E\Delta}{(1-\nu)}(T_{m4} - T)$$

$$= \pm 0.01537(M_3 + M_{T3})K_B + 0.02960 M_{T3} + 0.21098 E\Delta_{43} + 7.94782 P + 1.42857 E\Delta(T_{m4} - T)$$

POINTS 5 & 6:

$$\sigma_x = \left(\frac{T+V}{A}\right)K_T \pm \frac{M_2 c}{I} K_B = 0.31631(T+V)K_T \pm 0.36236 M_2 K_B$$

POINTS 7 & 8:

$$\sigma_x = \left(\frac{T+V}{A}\right)K_T \pm \frac{(M + R_1 \Delta_8)c}{I} K_B = 0.31631(T+V)K_T \pm 0.36236 M_2 K_B \pm 11.33489 H_2 K_B$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-151-P | A 87
SHEET 36 OF 51
CHARGE NO.
DATE 5-12-66 BY CARROLL
DESCRIPTION FATIGUE EVALUATION OF HEAD FLANGE, VESSEL FLANGE AND CLOSURE STUDS
CHECK DATE 5-12-66 BY ALEXANDER

5. DETAILED ANALYSIS:

e. STRESSES:

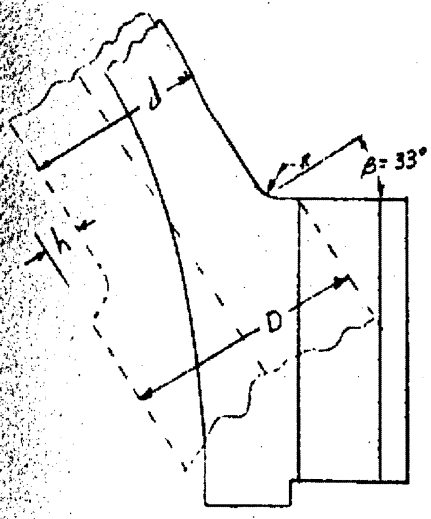
2. CONCENTRATED:

DETERMINATION OF STRESS CONCENTRATION FACTORS:

POINT-1

$K_T = K_B = 1$

POINT-2



$h = 2.181"$ $\quad R = 1.875"$
$D = 11.586"$
$d = 9.405"$
$\Delta = \frac{D}{d} = 1.232$

FROM REFERENCE - 4, WE HAVE

FOR TENSION

$$K_o = 1 + \left[\frac{1}{2.9\Delta - 2}\left(\frac{h}{R}\right)\right]^{0.65} = 1 + \left[\frac{1}{2.8(1.232) - 2}\left(\frac{2.181}{1.875}\right)\right]^{0.65}$$

$$= 1.866$$

$$K_T = 1 + (K_o - 1)\left[1 - \left(\frac{\beta}{90}\right)^{1 + 2.4\sqrt{R/h}}\right]$$

$$= 1 + (1.866 - 1)\left[1 - \left(\frac{33}{90}\right)^{1 + 2.4\sqrt{\frac{1.875}{2.181}}}\right]$$

$$= 1.832$$ ←

FOR BENDING:

$$K_o = 1 + \left[\frac{1}{5.37\Delta - 4.2}\left(\frac{h}{R}\right)\right]^{0.85} = 1 + \left[\frac{1}{5.37(1.232) - 4.2}\left(\frac{2.181}{1.875}\right)\right]^{0.85} = 1.685$$

$$K_B = 1 + (K_o - 1)\left[1 - \left(\frac{\beta}{90}\right)^{1 + 2.4\sqrt{R/h}}\right] = 1 + (1.685 - 1)\left[1 - \left(\frac{33}{90}\right)^{1 + 2.4\sqrt{\frac{1.875}{2.181}}}\right] = 1.659$$ ←

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION FATIGUE EVALUATION OF HEAD FLANGE, VESSEL FLANGE AND CLOSURE STUDS

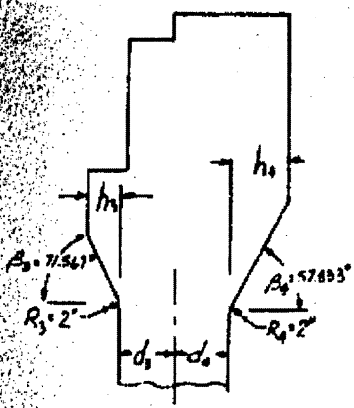
NUMBER 5-151-P | A 98
SHEET 27 OF 51
DATE 5-12-66 BY COCKRELL
CHECK DATE 5-12-66 BY ALEXANDER

5. DETAILED ANALYSIS:

e. STRESSES:

2. CONCENTRATED:

POINT-3:



$h_3 = 1.906"$ $\quad h_4 = 6.094"$
$D_3 = 7.281"$ $\quad D_4 = 11.469"$
$d_3 = 5.375"$ $\quad d_4 = 5.375"$
$\Delta_3 = \frac{D_3}{d_3} = 1.355$ $\quad \Delta_4 = \frac{D_4}{d_4} = 2.134$

FROM REF. 4, WE HAVE

FOR TENSION

$$K_0 = 1 + \left[\frac{1}{2.8\Delta_3 - 2}\left(\frac{h_3}{R_3}\right)\right]^{0.65} = 1 + \left[\frac{1}{2.8(1.355) - 2}\left(\frac{1.906}{2}\right)\right]^{0.65} = 1.663$$

$$K_T = 1 + (K_0 - 1)\left[1 - \left(\frac{\beta_3}{90}\right)^{1+2.4\sqrt{\frac{R}{h}}}\right] = 1 + (1.663 - 1)\left[1 - (0.795)^{1+2.4\sqrt{\frac{2}{1.906}}}\right] = \underline{1.363} \leftarrow$$

FOR BENDING:

$$K_0 = 1 + \left[\frac{1}{5.37\Delta_3 - 4.8}\left(\frac{h_3}{R_3}\right)\right]^{0.85} = 1 + \left[\frac{1}{5.37(1.355) - 4.8}\left(\frac{1.906}{2}\right)\right]^{0.85} = 1.444$$

$$K_B = 1 + (K_0 - 1)\left[1 - \left(\frac{\beta_3}{90}\right)^{1+2.4\sqrt{\frac{R}{h}}}\right] = 1 + (1.444 - 1)\left[1 - (0.795)^{1+2.4\sqrt{\frac{2}{1.906}}}\right] = \underline{1.243} \leftarrow$$

POINT-4:

FOR TENSION:

$$K_0 = 1 + \left[\frac{1}{2.8\Delta_4 - 2}\left(\frac{h_4}{R_4}\right)\right]^{0.65} = 1 + \left[\frac{1}{2.8(2.134) - 2}\left(\frac{6.094}{2}\right)\right]^{0.65} = 1.841$$

$$K_T = 1 + (K_0 - 1)\left[1 - \left(\frac{\beta_4}{90}\right)^{1+2.4\sqrt{\frac{R}{h}}}\right] = 1 + (1.841 - 1)\left[1 - (0.643)^{1+2.4\sqrt{\frac{2}{6.094}}}\right] = \underline{1.547} \leftarrow$$

FOR BENDING:

$$K_0 = 1 + \left[\frac{1}{5.37\Delta_4 - 4.8}\left(\frac{h_4}{R_4}\right)\right]^{0.85} = 1 + \left[\frac{1}{5.37(2.134) - 4.8}\left(\frac{6.094}{2}\right)\right]^{0.85} = 1.515$$

$$K_B = 1 + (K_0 - 1)\left[1 - \left(\frac{\beta_4}{90}\right)^{1+2.4\sqrt{\frac{R}{h}}}\right] = 1 + (1.515 - 1)\left[1 - (0.643)^{1+2.4\sqrt{\frac{2}{6.094}}}\right] = \underline{1.355} \leftarrow$$

POINTS 5, 6, 7, & 8:

$K_T = K_B = \underline{4}$ ← (FROM PAR. N-416.4, SECTION III NUCLEAR CODE)

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-157-P | A 09
SHEET 38 OF 51
CHARGE NO. _____
DATE 5-12-66 BY [illegible]
DESCRIPTION Failure Evaluation of Head Flange
CHECK DATE 5-12-66 BY [illegible]
Upper Flange Axi Closure Studs

5. Detailed Analysis:

a. Stresses:

2. Completed:

Location -1

Transient		Internal Pressure, psia	$(T_m - T)$ °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Peak Stress σ_x	Peak Stress σ_θ	Peak Stress σ_r	Stress Intensity $\sigma_x - \sigma_\theta$	Stress Intensity $\sigma_\theta - \sigma_r$	Stress Intensity $\sigma_\theta - \sigma_r$
Cold Bolt up		0	0	0	0	-21.50	-2.51	0	-21.50	-2.51	0	-18.99	-21.50	-2.51
Bolt up + 2500 psia		2.5	0	0	0	-11.99	6.17	-2.50	-11.99	6.17	-2.50	-18.16	-9.49	9.67
a Heatup	4.00 hrs	1.932		-17.50	-26.03	-14.35	4.02	-1.83	-31.85	-22.61	-1.83	-9.74	-29.97	-20.73
	4.25	2.078		-19.38	-27.93	-13.60	4.70	-2.09	-31.98	-23.23	-2.08	-8.70	-29.90	-21.20
	4.35	2.156		-19.37	-28.19	-13.31	4.97	-2.16	-31.69	-23.22	-2.16	-8.76	-29.52	-21.06
	4.47	2.250		-18.61	-28.73	-12.95	5.30	-2.25	-31.56	-23.43	-2.25	-8.13	-29.31	-21.18
	5.00	2.250		-13.80	-22.43	-12.95	5.30	-2.25	-26.75	-17.13	-2.25	-9.62	-24.50	-14.89
Steady State		2.250		-1.23	-0.59	-12.95	5.30	-2.25	-14.18	4.71	-2.25	-13.39	-11.93	6.96
b Cooldown	4.00 hrs	0.315		14.96	24.85	-20.30	-1.62	-0.32	-5.34	23.43	-0.32	-28.77	-5.02	23.75
	4.25			16.29	25.49				-4.01	24.07	-0.32	-29.08	-3.69	24.39
	4.35			16.43	25.74				-3.87	24.32	-0.32	-28.19	-3.55	24.64
	4.47			16.80	25.99				-3.50	24.87	-0.32	-27.97	-3.19	24.79
	5.00			11.69	19.66				-9.61	18.74	-0.32	-26.85	-9.29	18.56
c	20 min	2.250	-7.8	-3.63	-2.99	-12.95	5.30	-2.25	-16.58	2.31	-2.25	-18.89	-14.33	4.56
d	20 min	2.250	7.8	1.17	-1.81	-12.95	5.30	-2.25	-11.78	7.11	-2.25	-18.89	-9.53	9.36
e	100 sec	2.110	11.2	2.21	2.95	-13.37	4.92	-2.14	-11.16	7.77	-2.14	-19.93	-9.02	9.91
	225 sec	2.275	1.7	0.71	-0.07	-12.95	5.38	-2.29	-13.56	5.31	-2.29	-19.97	-11.23	7.59

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-151-P | A 90
SHEET 39 OF 51
DATE 5-12-66 BY
CHARGE NO.
CHECK DATE 5-17-66 BY
DESCRIPTION FATIGUE EVALUATION OF HEAD FLANGE VESSEL FLANGE AND CLOSURE STUDS

5. DETAILED ANALYSIS:
e. STRESS:
2. CONCENTRATED:

LOCATION - 1

Transient		Design Pressure psig	$(T_n - T)$ °F	Thermal Stress P_t	Thermal Stress T_t	Pressure Stress P_t	Pressure Stress T_t	Peak Stress P_t	Peak Stress T_t	Peak Stress P_t	Stress Intensity $T_t - T_r$	Stress Intensity $P_t - T_r$	Stress Intensity $T_t - P_t$
f	40 sec	2.320	-9.3	-4.09	-3.45	-12.68	5.54	-16.77	2.09	-2.32	-18.86	-14.45	4.41
	100 sec	2.260	-13.3	-5.31	-4.67	-12.91	5.33	-18.22	0.66	-2.26	-19.96	-15.96	2.92
	200 sec	2.140	-1.3	-1.63	-0.99	-13.37	4.92	-15.00	3.93	-2.14	-19.63	-12.86	6.07
g	2 min	2.370	-12.0	-4.92	-4.28	-12.49	5.71	-17.41	1.43	-2.37	-18.64	-15.04	3.80
	3.2 min	2.350	-15.0	-5.84	-5.20	-12.57	5.64	-18.41	0.44	-2.35	-18.85	-16.06	2.79
	4 min	2.150	0	-1.23	-0.59	-13.33	4.95	-14.56	4.36	-2.15	-13.92	-12.41	6.51
h	10 sec	2.220	-9.5	-4.15	-3.51	-13.06	5.19	-17.21	1.68	-2.22	-18.89	-14.99	3.90
	65 sec	1.910	8.5	1.38	2.02	-14.24	4.12	-12.86	6.14	-1.91	-17.80	-10.95	8.05
i	220 sec	3.125	0	0	0	-9.62	8.33	-9.62	8.33	-3.13	-11.95	-6.49	11.46
j	Major 35 hrs	1.250		-1.61	-2.73	-16.75	1.93	-3536	-26.90	-1.25	-9.46	-34.11	-25.65
	S.S.	2.500		-1.23	-0.59	-11.99	6.17	-13.21	5.58	-2.50	-18.30	-10.72	8.08
	Control 35 hrs	0.315		16.80	25.09	-2.30	-1.42	-3.50	24.47	-0.32	-27.97	-3.18	24.79
k	~	2.350	6.0	0.61	1.25	-12.57	5.64	-11.96	6.99	-2.35	-18.85	-9.16	9.24
	~	2.150	-6.0	-3.07	-2.43	-13.33	4.95	-16.40	2.52	-2.15	-18.92	-16.25	4.67
l	10 sec	2.150	33.3	9.40	9.64	-12.95	5.30	-3.95	14.94	-2.25	-13.89	-1.70	17.19
m	10 sec	2.760	-30.2	-10.51	-9.87	-11.09	7.07	-21.52	-2.90	-2.76	-19.72	-19.76	-0.04
	28 sec	2.170	-41.2	-13.88	-13.24	-13.44	4.85	-27.32	-9.39	-2.12	-19.93	-25.20	-6.27
	100 sec	1.440	4.8	0.24	0.88	-14.03	2.99	-15.79	3.37	-1.44	-19.16	-16.35	4.81
n	35 sec	0.300	117	34.71	35.35	-2.36	-1.97	14.35	33.88	-0.30	-19.53	14.65	34.18
	54 sec	0.760	197	59.18	59.92	-18.84	-0.08	40.44	59.84	-0.76	-19.40	41.14	60.56

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-151-P | A 91
SHEET 40 OF 51
CHARGE NO. ______
DATE 5-12-66 BY Campbell
DESCRIPTION Fatigue Evaluation of Head Flange Vessel Flange and Closure Studs
CHECK DATE 5-12-66 BY Alexander

5-Detailed Analysis:
e Stresses:
2. Concentrated:

Location -2

Transient		Internal Pressure ksia	(T_m-T) °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Peak Stress σ_x	Peak Stress σ_θ	Peak Stress σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	Stress Intensity $\sigma_x-\sigma_r$	Stress Intensity $\sigma_\theta-\sigma_r$
Cold Bolt up		0	0	0	0	38.63	18.16	0	38.63	18.16	0	20.47	38.63	18.16
Bolt up & 2500 psia		2.5	0	0	0	61.01	28.50		61.01	28.50		32.51	61.01	28.50
a Heatup	4.00 hrs.	1.832		23.13	7.76	55.40	25.94		78.61	33.70		44.91	78.61	33.70
	4.25	2.078		24.68	8.27	57.23	26.75		81.91	35.02		46.89	81.91	35.02
	4.35	2.156		24.62	8.19	57.93	27.08		82.55	35.27		47.28	82.55	35.27
	4.47	2.250		25.57	6.36	58.77	27.47		84.34	33.83		50.51	84.34	33.83
	5.00	2.250		20.54	6.09	58.77	27.47		79.31	33.56		45.75	79.31	33.56
Steady State		2.250		1.65	0.49	58.77	27.47		60.42	27.95		32.47	60.42	27.95
b Cooldown	4.00 hrs.	0.315		-13.62	-5.72	41.45	19.46		22.83	13.74		9.09	22.83	13.74
	4.25			-20.56	-6.54				20.89	12.92		7.97	20.89	12.92
	4.36			-19.87	-6.63				21.58	13.38		8.20	21.58	13.38
	4.47			-20.61	-6.46				20.84	13.00		7.84	20.84	13.00
	5.00			-17.70	-5.10				23.75	14.36		9.39	23.75	14.36
c	20 min	2.250	0	1.65	0.49	58.77	27.47		60.42	27.95		32.47	60.42	27.95
d	20 min	2.250				58.77	27.47		60.42	27.95		32.47	60.42	27.95
e	100 sec	2.160				57.79	27.01		59.44	27.49		31.95	59.44	27.49
	225 sec	2.275				59.00	27.57		60.65	28.05		32.60	60.65	28.05

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-1542 | A 92
SHEET 41 OF 51
CHARGE NO. _____ DATE 5-12-66 BY [illegible]
DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs CHECK DATE 5-12-66 BY [illegible]

5. Determine Allowables:
a. Stresses:
2. Concentrations:

LOCATION – 2

Transient		Internal Pressure psia	$(T_m - T)$ °F	Thermal Stress		Pressure Stress			Peak Stress			Stress Intensity		
				σ_z	σ_θ	σ_z	σ_θ	σ_r	σ_z	σ_θ	σ_r	$\sigma_z-\sigma_\theta$	$\sigma_z-\sigma_r$	$\sigma_\theta-\sigma_r$
f	60 sec	2.320	0	1.65	0.48	59.40	27.75	0	61.05	28.23	0	32.82	61.05	28.23
	100 sec	2.260				58.86	27.50		60.51	27.98		32.53	60.51	27.98
	260 sec	2.140				57.79	27.01		59.44	27.49		31.95	59.44	27.49
g	2 min	2.370				59.85	27.96		61.50	28.44		33.06	61.50	28.44
	3.2 min	2.350				59.67	27.88		61.32	28.36		32.96	61.32	28.36
	11.4 min	2.150				57.88	27.05		59.33	27.53		32.00	59.53	27.53
h	10 sec	2.320				58.50	27.34		60.15	27.82		32.33	60.15	27.82
	65 sec	1.910				55.73	26.06		57.38	26.54		30.84	57.38	26.54
i	220 min	3.125	↓	0	0	66.61	31.08		66.61	31.08		35.53	66.61	31.08
j	Heat up 25 hrs	1.250	X	25.57	6.36	49.82	23.33		75.39	29.69		45.70	75.39	29.69
	S.S.	2.500		1.65	0.48	61.01	28.50		62.66	28.98		33.69	62.66	28.98
	Cool down 35 hrs	0.315		-20.61	-6.46	41.45	19.44		20.84	13.00		7.84	20.84	13.00
k	~	2.350	0	1.65	0.48	59.67	27.88		61.32	28.36		32.96	61.32	28.36
	~	2.150				57.88	27.05		59.53	27.53		32.00	59.53	27.53
l	18 sec	2.250				58.77	27.47		60.42	27.95		32.47	60.42	27.95
m	10 sec	2.760				63.34	29.57		64.99	30.05		34.94	64.99	30.05
	29 sec	2.470				57.61	26.93		59.26	27.41		31.85	59.26	27.41
	160 sec	1.440				51.52	24.12		53.17	24.60		29.57	53.17	24.60
n	33 sec	0.300				41.32	19.40		42.97	19.88		23.09	42.97	19.88
	54 sec	0.760	↓	↓	↓	44.90	21.06	↓	46.55	21.54	↓	25.01	46.55	21.54

RIV000053D
Submitted: December 27, 2011

COMBUSTION ENGINEERING, INC.	NUMBER 5-151-P / A93
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.	SHEET 42 OF 51
CHARGE NO.	DATE 5-12-66 BY Cockrell
DESCRIPTION Fatigue Evaluation of Head Flange Vessel Flange and Closure Studs	CHECK DATE 5-12-66 BY Alexander

5. DETAILED ANALYSIS:

e. STRESSES:

2. CONCENTRATED:

Location -3

Transient		Internal Press. ksia	(T_m-T) °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Peak Stress σ_x	Peak Stress σ_θ	Peak Stress σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	Stress Intensity $\sigma_x-\sigma_r$	Stress Intensity $\sigma_\theta-\sigma_r$
Cold Bolt up		0	0	0	0	-25.23	-6.07	0	-25.23	-6.07	0	-19.16	-25.23	-6.07
Bolt up & 2500 psia		2.5	0	0	0	-10.93	12.93	-2.50	-10.96	12.83	-2.50	-23.79	-9.46	15.33
a Heatup	4.00 hrs	1.922		-7.05	-24.67	-14.49	8.16	-1.89	-21.54	-16.51	-1.89	-5.03	-19.66	-14.63
	4.25	2.079		-7.12	-25.24	-13.37	9.64	-2.08	-20.49	-15.60	-2.08	-4.89	-18.41	-13.52
	4.35	2.156		-6.56	-25.55	-12.93	10.23	-2.16	-19.47	-15.32	-2.16	-4.15	-17.31	-13.16
	4.47	2.250		-5.43	-25.02	-12.39	10.94	-2.25	-17.82	-14.08	-2.25	-3.74	-15.57	-11.83
	5.00	2.250		4.10	-17.95	-12.39	10.94	-2.25	-9.29	-7.01	-2.25	-1.28	-6.04	-4.76
Steady State		2.250		9.16	6.91	-12.39	10.94	-2.25	-3.21	11.85	-2.25	-15.06	-0.96	14.10
b Cooldown	4.00 hrs	0.315		13.41	23.95	-23.43	-3.69	-0.32	-10.02	20.26	-0.32	-30.28	-9.70	20.58
	4.25			12.76	24.28				-10.67	20.59	-0.32	-31.26	-10.35	20.91
	4.36			12.35	24.13				-11.08	20.44	-0.32	-31.52	-10.76	20.76
	4.47			13.19	25.15				-10.24	21.46	-0.32	-31.70	-9.92	21.78
	5.00			3.72	17.67				-19.71	13.98	-0.32	-33.69	-19.39	14.30
c	20 min	2.250	-7.8	4.79	-3.48	-12.39	10.94	-2.25	-7.60	7.46	-2.25	-15.06	-5.35	9.71
d	20 min	2.250	7.8	13.57	5.30	-12.39	10.94	-2.25	-1.18	16.24	-2.25	-15.06	3.43	18.49
e	100 sec	2.160	11.2	15.49	7.22	-13.02	10.11	-2.14	2.47	17.33	-2.14	-14.86	4.61	19.47
	225 sec	2.275	1.7	10.14	1.87	-12.25	11.13	-2.28	-2.11	13.00	-2.28	-15.11	0.17	15.29

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-151-P | A 94
SHEET 43 OF 51
CHARGE NO.
DATE 5-12-66 BY [illegible]
CHECK DATE 5-12-66 BY [illegible]

DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs

5- Detailed Analysis:
e- Stresses:
2- Concentrated:

Location - 3

Transient		Linear Result L/A	$(T_m - T)$ °F	Thermal Stress σ_t	Thermal Stress σ_θ	Pressure Stress σ_t	Pressure Stress σ_θ	Pressure Stress σ_r	Peak Stress σ_t	Peak Stress σ_θ	Peak Stress σ_r	Stress Intensity $\sigma_t-\sigma_\theta$	Stress Intensity $\sigma_t-\sigma_r$	Stress Intensity $\sigma_\theta-\sigma_r$
f	40 sec	2.320	-9.3	3.94	-4.33	-11.99	11.47	-2.32	-8.05	7.14	-2.32	-15.19	-5.73	9.46
	10 sec	2.260	-13.3	1.69	-6.59	-12.33	11.02	-2.26	-10.64	4.44	-2.26	-15.08	-9.39	6.70
	260 sec	2.160	-1.3	8.45	0.18	-13.02	10.11	-2.14	-4.57	10.29	-2.14	-14.86	-2.43	12.43
g	2 min	2.370	-12.0	2.42	-5.95	-11.71	11.85	-2.37	-9.29	6.00	-2.37	-15.29	-6.92	3.37
	3.2 min	2.350	-15.0	0.74	-7.53	-11.92	11.70	-2.35	-11.08	4.17	-2.35	-15.25	-9.73	6.62
	10.4 min	2.150	0	9.18	0.91	-12.96	10.19	-2.15	-3.78	11.10	-2.15	-14.88	-1.63	13.25
h	10 sec	2.220	-9.5	3.83	-4.44	-12.56	10.71	-2.22	-8.73	6.27	-2.22	-15.00	-6.51	8.49
	65 sec	1.910	8.5	13.97	5.70	-14.33	8.57	-1.91	-0.36	14.07	-1.91	-14.43	1.55	15.98
i	220 min	3.125	0	0	0	-7.40	17.56	-3.13	-7.40	17.56	-3.13	-24.96	-4.27	20.69
j	Heatup 35 hrs	1.250	X	-5.43	-25.02	-18.10	3.38	-1.25	-23.53	-21.64	-1.25	-1.89	-22.28	-20.39
	S.S.	2.500	X	9.18	0.91	-10.93	12.83	-2.50	-1.75	13.74	-2.50	-15.49	0.75	16.24
	Cooldown 35 hrs	0.315	X	13.19	25.12	-23.43	-3.69	-0.32	-10.24	21.46	-0.32	-31.70	-9.92	21.78
k	~	2.350	6.0	12.56	4.29	-11.82	11.70	-2.35	0.74	15.99	-2.35	-15.25	3.09	18.34
	~	2.150	-6.0	5.80	-2.47	-12.96	10.19	-2.15	-7.16	7.72	-2.15	-14.88	-5.01	9.87
l	12 sec	2.250	33.3	27.93	19.66	-12.39	10.94	-2.25	15.54	30.60	-2.25	-15.06	17.79	32.85
m	16 sec	2.760	-30.2	-7.82	-16.09	-9.48	14.80	-2.76	-17.30	-1.29	-2.76	-16.01	-14.54	1.47
	25 sec	2.120	-41.2	-14.02	-22.29	-13.13	9.96	-2.12	-27.15	-12.33	-2.12	-14.82	-25.03	-10.21
	163 sec	1.440	4.8	11.88	3.61	-17.01	4.82	-1.44	-5.13	8.43	-1.44	-13.56	-3.69	9.87
n	33 sec	0.300	117	75.05	66.78	-23.52	-3.90	-0.30	51.53	62.88	-0.30	-11.35	51.83	63.28
	54 sec	0.700	197	120.09	111.82	-21.24	-0.78	-0.70	98.85	111.04	-0.70	-12.19	99.55	111.74

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-151-P | A 95
SHEET 44 OF 51
CHARGE NO.
DATE 5-12-06 BY LOCKER
DESCRIPTION Fatigue Evaluation of Head Flange Lower Flange and Closure Studs
CHECK DATE 5-11-06 BY BLEIMEIER

5. Detailed Analysis:

e. Stresses:

2- Concentrated:

Location - 4

Transient	Internal Pressure psig	$(T_{m1}-T)$ °F	Thermal Stress σ_x	Thermal Stress σ_θ	Thermal Stress σ_r	Peak Stress σ_x	Peak Stress σ_θ	Peak Stress σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	Stress Intensity $\sigma_x-\sigma_r$	Stress Intensity $\sigma_\theta-\sigma_r$
Cold Start-up	0	0	0	0	0	27.10	9.63	0	17.47	27.10	9.63
Full load 250 psig	2.5	0	0	0		37.55	27.56		11.99	37.55	27.56
a 100 hrs	1.822		-7.25	-5.56		36.40	22.13		6.66	29.23	22.57
1.15	2.078		-7.31	-3.57		37.45	24.54		6.17	30.14	23.97
4.35	2.156		-7.55	-0.34		37.84	15.47		6.04	30.29	24.25
4.47	2.250		-9.14	-0.02		38.31	25.77		1.02	29.17	25.15
5.00	2.250		-14.63	-4.26		38.31	25.77		2.17	23.69	21.51
Steam Spike	2.850		-10.26	-4.05		38.31	25.77		6.33	28.05	21.72
b 100 hrs	0.515		-0.66	-2.46		28.67	11.89		16.78	29.01	9.43
4.15			-0.55	-2.19					16.57	29.12	9.75
4.35			2.21	-1.90					16.97	29.88	9.91
4.47			0.45	-1.19					16.92	29.12	10.70
5.00			4.90	1.40					20.0	33.47	13.37
c 20 min	2.250	0	-10.26	-4.05		38.31	25.77		6.33	28.05	21.72
d 20 min	2.250					38.31	25.77		6.33	28.05	21.72
e 80 sec	2.110					37.76	24.98		6.57	27.50	20.93
225 sec	2.275					38.43	25.95		6.27	28.17	21.90

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-151-P | A-96
SHEET 45 OF 51
CHARGE NO. ______
DATE 5-12-66 BY [illegible]
CHECK DATE 5-12-66 BY [illegible]

DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs

5. Detailed Analysis:
e. Stresses:
2. Concentrated:

LOCATION - 4

Transient		Internal Pressure KSIA	$(T_m - T)$ °F	Thermal Stress σ_x	Thermal Stress σ_θ	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Peak Stress σ_x	Peak Stress σ_θ	Peak Stress σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	Stress Intensity $\sigma_x-\sigma_r$	Stress Intensity $\sigma_\theta-\sigma_r$
f	40sec	2.320	0	-10.26	-4.05	38.66	26.27	0	28.40	22.22	0	6.18	28.40	22.22
	100sec	2.260	↓	↓	↓	38.36	25.86	↓	28.10	21.79	↓	6.31	28.10	21.79
	260sec	2.140				37.76	24.98		27.50	20.93		6.57	27.50	20.93
g	2 min	2.370				39.91	26.63		28.65	22.58		6.07	28.65	22.58
	3.2 min	2.350				39.91	26.49		28.55	22.44		6.11	28.55	22.44
	10.4 min	2.150				37.81	25.05		27.55	21.00		6.55	27.55	21.00
h	18sec	2.220				38.16	25.55		27.90	21.50		6.40	27.90	21.50
	65sec	1.910				36.16	23.33		26.35	19.28		7.07	26.35	19.28
i	230 min	3.125		0	0	42.67	32.05		42.67	32.05		10.62	42.67	32.05
j	Heatup 35hrs	1.250	X	-9.14	-6.66	33.33	18.59		24.19	17.97		6.22	24.19	17.97
	S.S.	2.500		-10.26	-4.05	39.55	27.56		29.29	23.51		5.78	29.29	23.51
	Cooldown 35hrs	0.315		0.65	-1.19	28.67	11.89		29.12	10.70		18.42	29.12	10.70
k	~	2.350	0	-10.26	-4.05	38.81	26.49		28.55	22.44		6.11	28.55	22.44
	~	2.150	↓	↓	↓	37.81	25.05		27.55	21.00		6.55	27.65	21.00
l	125"	2.350				38.31	25.77		29.05	21.72		6.33	29.05	21.72
m	10sec	2.760				40.45	29.43		30.59	25.38		5.21	30.59	25.38
	28sec	2.120				37.66	24.84		27.40	20.79		6.61	27.40	20.79
	160sec	1.440				34.27	19.96		24.01	15.91		8.10	24.01	15.91
n	33sec	0.300				28.59	11.78		18.33	7.73		10.60	18.33	7.73
	54sec	0.760				30.59	14.65		20.33	10.60		9.73	20.33	10.60

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.______

DESCRIPTION: Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs

NUMBER: 5-151-P | A 97
SHEET 46 OF 51
DATE 5-12-66 BY: [illegible]
CHECK DATE 5-12-66 BY: [illegible]

5. Detailed Analysis:

e. Stresses:

2. Concentrated:

Transient		Location 5 σ_r	Location 6 σ_r	Location 7 σ_r	Location 8 σ_r
f	30 sec	197.53	130.64	229.16	99.52
	60 sec	195.72	131.45	229.20	97.92
	120 sec	191.30	134.12	231.20	94.72
g	5 min	199.23	129.33	227.32	100.84
	3.2 min	192.64	129.36	227.63	100.32
	8.4 min	192.12	133.39	231.04	94.46
h	10 sec	192.80	132.32	229.84	96.84
	65 sec	184.29	129.36	225.08	99.56
i	220 min	221.56	134.20	222.33	105.09
j	Heatup 3.5 hrs	170.96	137.24	383.48	-26.00
	S.S.	222.52	125.96	225.16	104.32
	Cooldown 3.5 hrs	111.40	133.23	143.08	101.72
k	~	192.64	129.36	227.69	66.32
	~	192.12	133.33	231.04	94.96
l	10 sec	195.36	131.64	229.36	97.64
m	10 sec	212.00	130.04	220.76	111.28
	23 sec	191.12	134.55	[illegible]	94.16
	160 sec	168.76	150.04	242.96	76.00
n	33 sec	131.64	175.92	262.16	45.56
	54 sec	144.84	166.30	255.44	56.24

Transient		Location 5 σ_r	Location 6 σ_r	Location 7 σ_r	Location 8 σ_r
Cold		119.64	175.24	273.24	21.64
Startup + 3500		201.16	119.44	231.20	23.40
a	4.3 hrs	135.04	179.20	367.16	-6.72
	4.45 hrs	197.20	168.36	364.34	2.72
	4.85	202.36	164.64	363.40	3.56
	4.97	203.56	164.56	366.64	1.48
	5.30	217.12	161.48	360.68	17.92
Steady State		195.36	131.64	229.36	97.64
b	4.30 hrs	120.68	136.44	151.52	105.72
	4.25	117.60	133.00	144.84	105.89
	4.35	114.60	134.68	145.24	104.16
	4.47	111.40	133.28	143.08	101.72
	5.03	96.56	140.68	152.92	84.44
c	20 min	195.36	131.64	229.36	97.64
d	20 min	195.36	131.64	229.36	97.64
e	80 sec	191.80	134.12	231.20	94.72
	[illegible] sec	196.20	131.04	229.92	94.32

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. _____

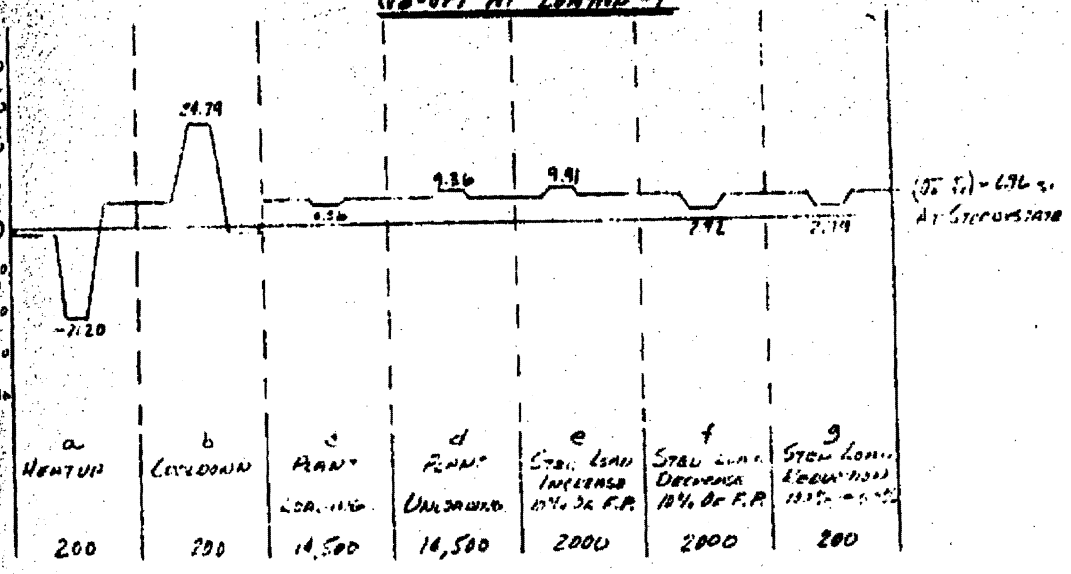
DESCRIPTION Fatigue Evaluation of Head Flange Vessel Flange and Closure Studs

NUMBER S-151-P | A98
SHEET 47 OF 51
DATE 5-12-66 BY COTTRELL
CHECK DATE 5-12-66 BY ALEXANDER

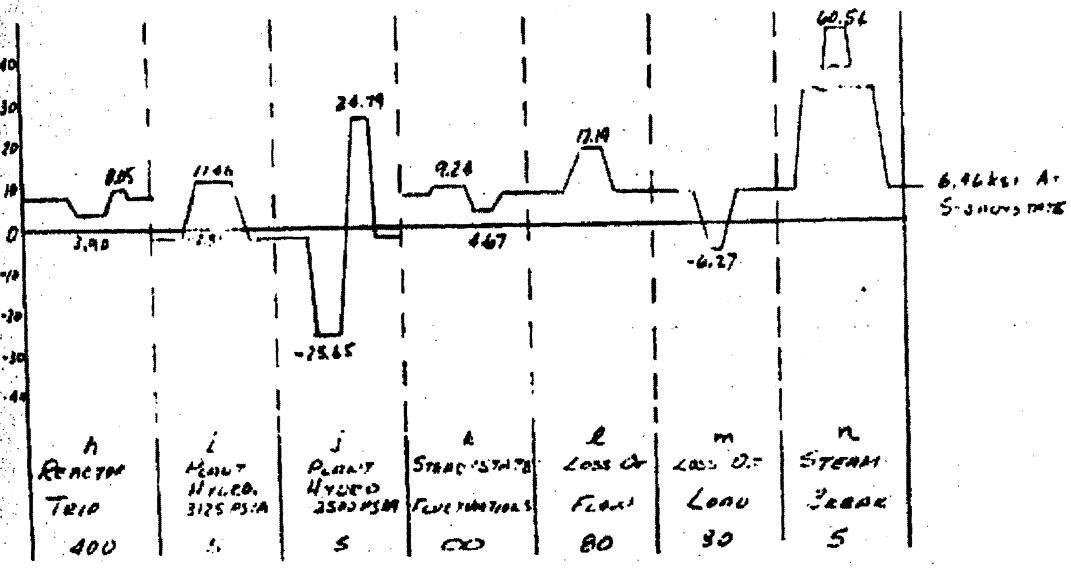
5. Detailed Analysis:

f. Fatigue Evaluation:

$(S_o - S_i)$ At Location - 1



a	b	c	d	e	f	g
Heatup	Cooldown	Plant Load.	Plant Unloading	Steady Load Increase 10% of F.P.	Steady Load Decrease 10% of F.P.	Steady Load Load Reversal
200	200	14,500	14,500	2000	2000	200



h	i	j	k	l	m	n
Reactor Trip	Plant Hydro. 3125 psia	Plant Hydro 2500 psia	Steady State Fluctuations	Loss of Flow	Loss of Load	Steam Leak
400	5	5	∞	80	80	5

S_{max}	S_{min}	Number of Occurrences	S_{alt}	N^*	U
60.56	- 25.65	5	43.1	6600	0.00075
24.79	- 21.20	195	23.0	56000	0.00348
17.19	- 6.27	80	11.7	∞	0

* From Fig. N-415(a)
Interpolate 1

$U_{overall}$ = 0.00423

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. _____

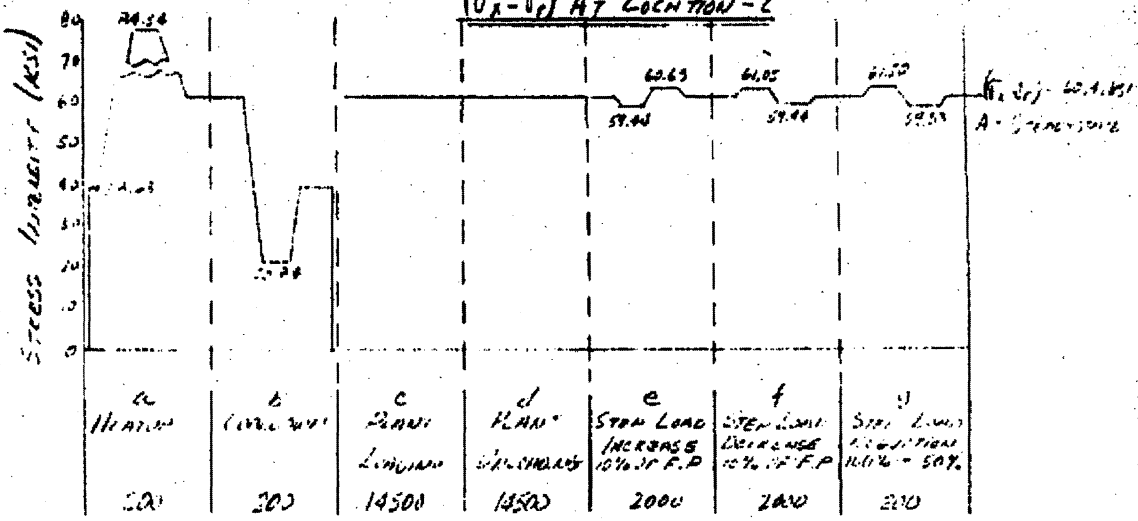
DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs

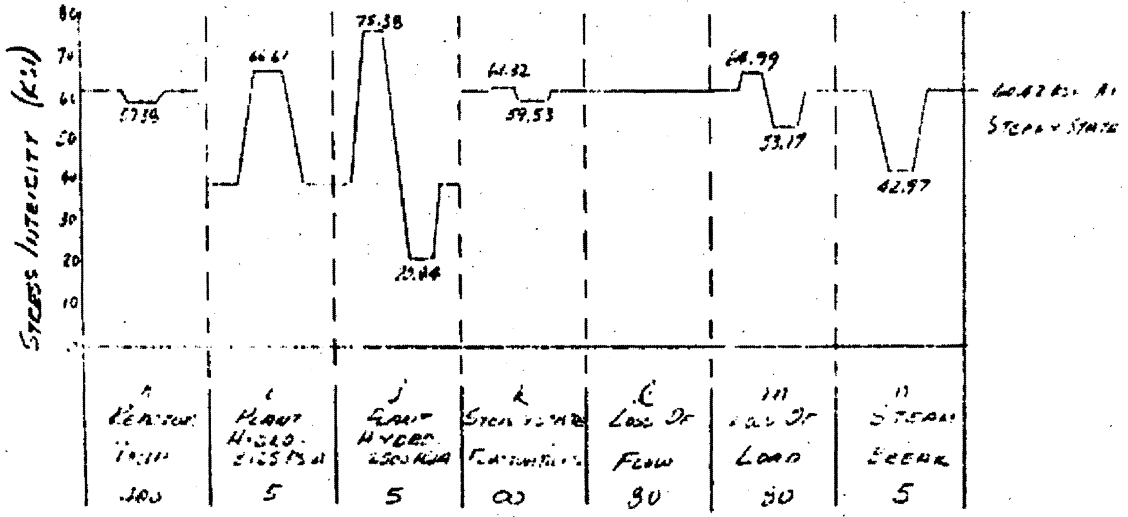
NUMBER S-151-P | L 99
SHEET 48 OF 51
DATE 5-12-66 BY Correll
CHECK DATE 5-12-66 BY Alexander

5. Detailed Analysis:

1. Fatigue Evaluation:

$(\sigma_1 - \sigma_2)$ At Location - 2





S_{max}	S_{min}	Number of Occurrences	S_{alt}	N^*	U
74.54	0	40	42.3	7000	0.00571
66.61	29.84	160	31.9	19000	0.00842
75.38	29.84	5	27.3	30000	0.00016
64.99	59.63	5	14.0	600000	0.00001
64.99	42.97	5	11.0	∞	0

$U_{total} = 0.01476$

* From Fig. N-415(a) Reference 1