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

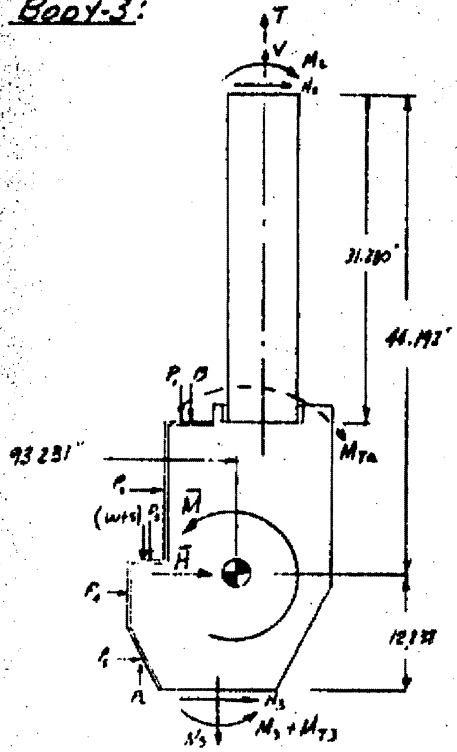
NUMBER S-151-P | A-63
SHEET 14 OF 51
DATE 5-12-66 BY Cockrell
CHECK DATE 5-12-66 BY Alexander

5. Detailed Analysis:

d. Development Of Continuity Equations:

2. Movements Due To Loads:

Body-3:



$I = 20945\ in^4$
$A = 378.957\ in^2$
$\frac{R^2}{I} = 0.41409$
$\frac{R^2}{A} = 22.9367$

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

$\bar{M} = -15.4751 H_2 - 1.0290 M_2 - 1.0136 M_{T2} + 12.5351 H_3$
$+ 0.9765 (M_3 + M_{T3}) + 7.1372 (T+V)$
$+ 7.8499 (W+S) - 79.8729 P$

Displacements Due To Redundant Forces:

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

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

$E\Delta_{13} = \frac{R^2}{A}\bar{H} - h_1 \frac{R^2}{I}\bar{M} = -218.6730 H_2 - 5.4818 M_2 + 89.1774 H_3 + 5.2020 M_3 + 38.0249 V$

$E\Delta''_{13} = \frac{R^2}{I}\bar{M} = -19.8717 H_2 - 0.4270 M_2 + 5.2019 H_3 + 0.4052 M_3 + 2.9619 V$

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

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

NUMBER S-151-D | A'66
SHEET 15 OF 51
DATE 5-12-66 BY COZZUOLI
CHECK DATE 5-12-66 BY ALEXANDER

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

DISPLACEMENTS DUE TO APPLIED FORCES:

$E\delta_{33}' = \frac{R^2}{A}\bar{H} - h_j\frac{R^2}{I}\bar{M} = -130.8923T - 143.9612(W+S) + 2009.1891P$

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

$E\delta_{33}' = \frac{R^2}{A}\bar{H} - h_j\frac{R^2}{I}\bar{M} = 39.0249T + 41.8215(W+S) + 118.8449P$

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

$E\upsilon_{31} = 6.936\frac{R^2}{I}\bar{M} = -229.9041P$

DISPLACEMENTS DUE TO THERMAL EFFECTS:

$E\delta_{33T}' = R_3 E\alpha(T_m - 70) - R_3 h_1 E\alpha\left(\frac{\Delta T}{\Delta x}\right)_{eq} - h_j\frac{R^2}{I}\bar{M} =$

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

$E\delta_{32T}^{\phi} = R_3 E\alpha\left(\frac{\Delta T}{\Delta x}\right)_{eq} + \frac{R^2}{I}\bar{M} = 93.231E\alpha\left(\frac{\Delta T}{\Delta x}\right)_{eq} + 0.4052M_{T3} - 0.4197M_{Ta}$

$E\delta_{33T}' = R_4 E\alpha(T_{beq} - 70) + h_j\frac{R^2}{I}\bar{M} = 91.031E\alpha(T_{beq} - 70) + 5.2020M_{T3} - 5.3884M_{Ta}$

$E\delta_{32T}^{\phi} = R_3 E\alpha\left(\frac{\Delta T}{\Delta x}\right)_{eq} + \frac{R^2}{I}\bar{M} = 93.231E\alpha\left(\frac{\Delta T}{\Delta x}\right)_{eq} + 0.4052M_{T3} - 0.4197M_{Ta}$

$E\upsilon_{31T} = R_6 E\alpha(T_6 - 70)\frac{E_{SA}}{E_{WA}} 16.936\frac{R^2}{I}\bar{M} =$

$= 30.6221E\alpha(T_6 - 70) + 646.6502E\alpha\left(\frac{\Delta T}{\Delta x}\right)_{eq} + 2.8105M_{T3} - 2.9112M_{Ta}$

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.

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 68*
SHEET *17* OF *51*
DATE *5-12-66* BY *[illegible]*
CHECK DATE *5-12-66* BY *Alexander*

5. Detailed Analysis:
d. Development Of Continuity Matrix:
2. Movements Due To Loads:

Transient		(T−70)	(Eα)	(T−70)	(Eα)	(T−70)	(Eα)m	$(\Delta T/\Delta T_{avg})$	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	180	6.539	459071	1023212	9702337	-132299	2078537	-132289	-339472
	4.25	215	184	334	185	113	180	6.849	461449	1069279	10581097	-144324	2263799	-144324	-356069
	4.35	253	184	342.8	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	297	184	390.3	186	160	181	7.113	361170	1176806	15080433	-225563	2149524	-225563	-703782
Steady state		463	186	476.8	186	462	186	1.064	17291	361003	13599949	-126063	6217775	-126063	1833059
Cool down	4.00 hrs	280	184	193.8	182	389	186	-5.582	-402539	-726730	2523090	46158	5026108	46158	2549787
	4.25	247	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	1128053	66740	4823010	66740	2654689
	4.87	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

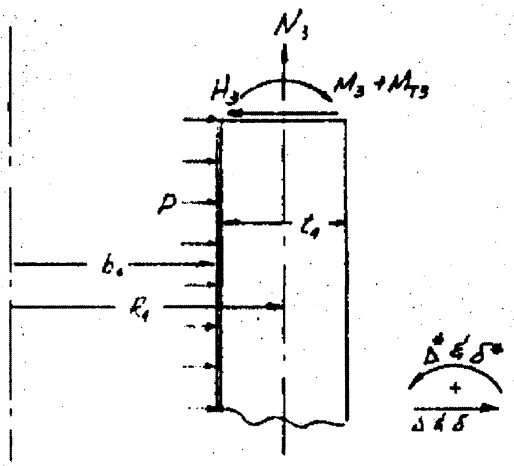
NUMBER S-151-P | A 69
SHEET 18 OF 51
DATE 5-12-66 BY COCKRELL
CHECK DATE 5-12-66 BY ALEXANDER

5. DETAILED ANALYSIS:

d. DEVELOPMENT OF CONTINUITY EQUATIONS:

2. MOVEMENTS DUE TO FORCES:

BODY-4:



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

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

$\beta = 0.04108$

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

DISPLACEMENTS DUE TO REDUNDANT FORCES:

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

$$E\Delta^*_{43} = -\frac{E}{2\beta^3 D}\left[-H_3 + 2\beta M_3\right] = 2.6006H_3 - 0.2137M_3$$

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:

$$E\delta_{43T} = R_4 E\alpha\left(T_{43} - 70\right) + \frac{E}{2\beta^3 D}M_{T3} = 91.031E\alpha\left(T_{43} - 70\right) + 2.6006M_{T3}$$

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

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 51
DATE 5-12-66 BY
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

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

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

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:

162.1377	2.2709	92.6039	3.9830	0	0	-27.6228	H_1
2.2709	0.9094	-5.0262	-0.3190	0	0	2.3123	M_1
-72.3659	4.4029	-2018.0589	-74.7959	207.4870	17.9066	165.7537	H_2
3.4293	-0.2794	74.7959	4.0005	-5.2019	-0.4052	-5.1742	M_2
0	0	-218.6730	-5.4818	152.4692	2.6013	39.0249	H_3
0	0	-18.8717	-0.4270	2.6013	0.6189	2.7619	M_3
24.1997	-1.9379	165.7558	5.1743	-36.0804	-2.8105	-48.1249	V

HEAT UP / STEADY STATE

T=4.00	T=4.25	T=4.35	T=4.57	T=5.00	STEADY STATE
-2212,270	-2296,590	-2331,160	-2367,380	-2105,180	-12,000
-236,550	-234,790	-234,050	-233,770	-165,500	-4,810
3933,219	4326,047	4835,205	5267,348	5313,263	5097,179
-44,929	-56,284	-66,435	-76,072	-158,163	-121,723
4518,598	4712,617	4916,004	5034,757	5494,714	1852,849
91,550	92,860	103,220	119,630	199,170	125,750
-1182,242	-1304,099	-1391,680	-1481,383	-2079,022	-366,941

COOL DOWN

T=4.00	T=4.25	T=4.35	T=4.47	T=5.00
2096,790	2137,860	2167,270	2181,990	1958,810
195,740	197,030	196,920	196,960	134,550
-709,320	-1292,952	-1589,907	-1849,120	-4630,996
-26,902	-13,648	-7,340	-908	72,437
-3041,073	-3314,153	-3396,461	-3538,587	-3863,384
-3,210	-16,350	-24,010	-26,970	-101,400
671,377	820,286	880,239	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:

4. 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: KIPS PER INCH OF CIRCUMFERENCE
M's: IN-KIPS PER INCH OF CIRCUMFERENCE
V's: KIPS PER INCH OF CIRCUMFERENCE

} APPLIED AT THEIR RESPECTIVE RADII.

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

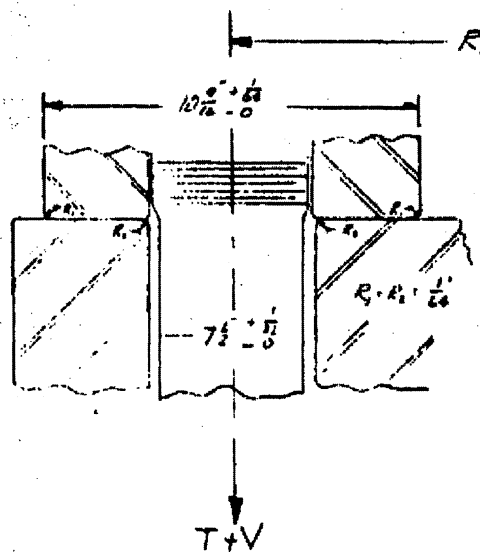
NUMBER 5-151-P | A 73
SHEET 22 OF 51
CHARGE NO.
DATE 5-12-66 BY CRUMRINE
DESCRIPTION FATIGUE EVALUATION OF HEAD FLANGE VESSEL FLANGE AND CLOSURE STUDS
CHECK DATE 5-12-66 BY ALEXANDER

5. DETAILED ANALYSIS:

e. STRESSES:

1. UNCOUPLED TRANSIENT:

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.]

$= \left[\frac{116.732 + 3.986670 - 4.271}{54}\right] 2\pi R_B$

= 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"

Required Area Per Stud = $\frac{\pi}{4}\left[10.5312^2 - 7.5625^2\right]$ = 42.19 in.²

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

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

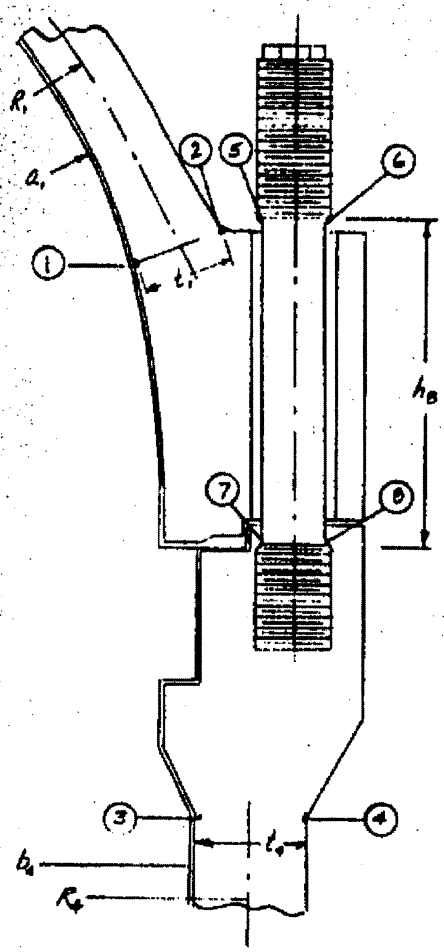
DESCRIPTION FATIGUE EVALUATION OF HEAD FLANGE, VESSEL FLANGE AND CLOSURE HEAD

5. DETAILED ANALYSIS:

e. STRESSES:

1. UNCONCENTRATED:

STRESSES WILL BE CALCULATED AT THE LOCATIONS AS SHOWN BELOW.



POINTS 1 & 2:

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

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

$$\sigma_\theta = \pm \frac{\nu t_1}{t_1^2}(M_1 + M_{T1}) + \frac{\nu H_1 \cos\theta}{t_1} + \frac{E\Delta_{11} + E\delta_{11T}}{R_1 \sin\theta} + \frac{t_1 \cos\theta (E\Delta_{11}^{\alpha} + E\delta_{11T}^{\alpha})}{2R_1 \sin\theta} + \frac{a_1 P}{2R_1 t_1} + \frac{E\alpha (T_{m1} - T)}{(1-\nu)} - E\alpha (T_{m1} - 70) = \pm 1.02035 (M_1 + M_{T1}) + 0.01096 H_1 + 0.01189 (E\Delta_{11} + E\delta_{11T}) \pm 0.01922 (E\Delta_{11}^{\alpha} + E\delta_{11T}^{\alpha}) + 4.3709 P + 1.42857 E\alpha (T_{m1} - T) - E\alpha (T_{m1} - 70)$$

POINTS 3 & 4:

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

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

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

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:

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

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

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

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.

NUMBER 5-151-P | A 76
SHEET 85 OF 51
DATE 5-12-66 BY Carrell
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:

Location 1

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	-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	8.67
a Heatup	4.00 hrs	1.892		-17.50	-26.63	-14.25	4.02	-1.88	-31.35	-22.61	-1.83	-9.24	-29.97	-20.73
	4.25	2.078		-19.38	-27.98	-13.60	4.70	-2.08	-31.93	-23.29	-2.08	-8.70	-29.90	-21.20
	4.35	2.156		-18.37	-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	-14.88
Steady State		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 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	-28.09	-3.69	24.39
	4.35	↓		16.83	25.76	↓	↓	↓	-3.87	24.32	-0.32	-28.19	-3.55	24.64
	4.47	↓		16.80	25.89	↓	↓	↓	-3.50	24.47	-0.32	-27.97	-3.18	24.79
	5.00	↓		11.69	19.66	↓	↓	↓	-8.61	18.24	-0.32	-26.85	-8.29	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	30 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	2.160	11.2	2.21	2.85	-13.37	4.92	-2.14	-11.16	7.77	-2.14	-18.93	-9.02	9.91
	225 sec	2.275	1.7	-0.71	-0.07	-12.85	5.38	-2.28	-13.56	5.31	-2.28	-18.87	-11.28	7.59

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-151-P | A 77

SHEET 26 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-Detailed Analysis:

e-Stresses:

1. Unconcentrated:

Location - 1

Transient		Internal Pressure psia	(T_m-T) °F	Thermal Stress σ_t	Thermal Stress σ_θ	Pressure Stress σ_t	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_t	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_t-\sigma_\theta$	Stress Intensity $\sigma_t-\sigma_r$	Stress Intensity $\sigma_\theta-\sigma_r$
f	40sec	2.320	-9.3	-4.19	-3.45	-12.69	5.54	-2.32	-16.77	2.09	-2.32	-18.86	-14.45	4.41
	100sec	2.260	-13.3	-5.31	-4.67	-12.91	5.33	-2.26	-18.22	0.66	-2.26	-18.88	-15.96	2.92
	260sec	2.160	-1.3	-1.63	-0.99	-13.37	4.92	-2.16	-15.00	3.93	-2.16	-18.93	-12.96	6.07
g	2 min	2.370	-12.0	-4.92	-4.28	-12.49	5.71	-2.37	-17.41	1.43	-2.37	-18.84	-15.04	3.90
	3.2 min	2.350	-15.0	-5.84	-5.20	-12.67	5.64	-2.35	-18.41	0.44	-2.35	-18.85	-16.06	2.79
	10.4 min	2.150	0	-1.23	-0.59	-13.33	4.95	-2.15	-14.56	4.36	-2.15	-18.92	-12.41	6.51
h	10sec	2.220	-9.5	-4.15	-3.51	-13.06	5.19	-2.22	-17.21	1.68	-2.22	-18.89	-14.99	3.90
	65sec	1.910	8.5	1.38	2.02	-14.24	4.12	-1.91	-12.86	6.14	-1.91	-19.00	-10.95	8.05
i	220 min	3.125	0	0	0	-9.62	8.33	-3.13	-9.62	8.33	-3.13	-17.95	-6.49	11.46
j	Heatup 3.5 hrs	1.250	X	-19.61	-28.73	-16.75	1.93	-1.25	-35.36	-26.90	-1.25	-8.46	-34.11	-25.65
	S.S.	2.500	X	-1.23	-0.59	-11.99	6.17	-2.50	-13.22	5.58	-2.50	-18.80	-10.72	8.08
	Cooldown 3.5 hrs	0.315	X	16.80	25.89	-20.30	-1.42	-0.32	-3.50	24.47	-0.32	-27.97	-3.18	24.79
k	~	2.350	6.0	5.61	1.25	-12.57	5.64	-2.35	-11.96	6.89	-2.35	-18.85	-9.16	9.24
	~	2.150	-6.0	-3.07	-2.43	-13.33	4.95	-2.15	-16.40	2.52	-2.15	-18.92	-14.25	4.64
l	12sec	2.250	33.3	9.00	9.64	-12.95	5.30	-2.25	-3.95	14.94	-2.25	-18.99	-1.70	17.19
m	10sec	2.760	-30.2	-10.51	-9.87	-11.01	7.07	-2.76	-21.52	-2.80	-2.76	-18.72	-18.76	-0.04
	25sec	2.120	-41.2	-13.88	-13.24	-13.44	4.55	-2.12	-27.32	-9.39	-2.12	-18.93	-25.20	-7.27
	160sec	1.440	4.9	0.24	0.88	-16.03	2.49	-1.44	-15.79	3.37	-1.44	-19.16	-14.35	4.81
n	33sec	0.300	117	34.71	35.35	-20.36	-1.47	-0.30	14.35	33.88	-0.30	-19.53	14.65	34.18
	54sec	0.700	197	59.28	59.92	-18.84	-0.08	-0.70	40.44	59.84	-0.70	-19.40	41.14	60.54

$S.I._{\substack{max \\ range}} = (\sigma_\theta - \sigma_r) = 50.40\,ksi < 3S_m = 80.1\,ksi$ (Criterion 5-c-2)

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

CHARGE NO. ______

NUMBER 5-151-P | A 78
SHEET 27 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:

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	1.822		12.25	8.53	32.49	21.31		44.74	29.34		14.40	44.74	29.34
	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	7.79		6.11	13.89	7.79
	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	23.09	↓	12.22	35.30	23.09
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 5-151-P | A-79
SHEET 28 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 Alexander

5- Detailed Analysis:

e- Stresses:

1- Unconcentrated:

LOCATION - 2

Transient		Location Pressure ksi	$(T_m - T)$ °F	Thermal Stress σ_t	Thermal Stress σ_θ	Pressure Stress σ_t	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_t	Total Stress σ_θ	Total 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	0	0.99	0.29	34.66	23.07	0	35.65	23.36	0	12.29	35.65	23.36
	102 sec	2.260				34.36	22.83		35.35	23.12		12.23	35.35	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	23.28		35.89	23.57		12.32	35.89	23.57
	3.2 min	2.350				34.80	23.19		35.79	23.48		12.31	35.79	23.48
	10.4 min	2.150				33.82	22.39		34.81	22.68		12.13	34.81	22.68
h	10 sec	2.220				34.16	22.67		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
i	230 min	3.125		0	0	39.63	26.31		38.63	26.31		12.32	38.63	26.31
j	Heatup 35 hrs	1.250	X	13.54	7.20	29.37	19.77		42.91	25.97		16.94	42.91	25.97
	S.S.	2.500	X	0.99	0.29	35.54	23.80		36.53	24.09		12.44	36.53	24.09
	Cooldown 35 hrs	0.315	X	-10.87	-7.23	26.76	15.01		13.89	7.79		6.11	13.89	7.78
k	~	2.350	0	0.99	0.29	34.80	23.19		35.79	23.48		12.31	35.79	23.48
	~	2.150				33.82	22.39		34.81	22.68		12.13	34.81	22.68
l	12 sec	2.250				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	2.120				33.67	22.27		34.66	22.56		12.10	34.66	22.56
	160 sec	1.490				30.31	19.53		31.30	19.82		11.48	31.30	19.82
n	33 sec	1.300				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

$SI_{max\ range} = (\sigma_x - \sigma_r) = 47.85\ ksi < 3S_m = 80.1\ ksi$ (Criteria 5-C-2

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	14.22	-2.50	-23.94	-7.22	16.72
a Heatup	4.00 hrs.	1.892		-3.10	-26.29	-12.34	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	-13.88
	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	0.30	-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	↓		8.90	25.49	↓	↓	↓	-11.07	23.27	-0.32	-34.34	-10.75	23.59
	4.35	↓		8.55	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	2.160	11.2	10.92	3.74	-11.25	11.51	-2.14	-0.33	15.25	-2.14	-15.58	1.81	17.39
	225 sec	2.275	1.7	8.00	0.92	-10.68	12.53	-2.28	-2.65	13.35	-2.28	-16.03	-0.40	15.63

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 91
SHEET: 30 OF 51
DATE: 5-12-66 BY: [illegible]
CHECK DATE: 5-17-66 BY: Alexander

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 $\sigma_\theta-\sigma_r$
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	9.95	-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	8.79	-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 35 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	7.48	0.30	-9.72	14.22	-2.50	-2.24	14.52	-2.50	-16.56	0.26	17.02
	Cooldown 35 hrs	0.315	X	9.18	26.38	-19.97	-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	2.250	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	2.120	-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	1.440	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	67.99	60.81	-17.34	0.68	-0.70	50.65	61.49	-0.70	-10.84	51.35	62.[illegible]

$S.I._{max\ range} = (\sigma_\theta - \sigma_r) = 45.35$ 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	X	-7.92	1.91	26.38	21.19	↓	18.46	22.99	↓	-4.53	18.46	22.99
	4.25	2.078	X	-9.04	1.36	27.01	22.60	↓	18.97	24.46	↓	-5.49	18.97	24.46
	4.35	2.156	X	-9.27	1.65	27.26	23.16	↓	18.99	24.91	↓	-5.32	18.99	24.91
	4.47	2.250	X	-9.52	2.02	27.56	23.84	↓	19.04	25.86	↓	-7.92	19.04	25.86
	5.00	2.250	X	-13.04	-1.64	27.56	23.84	↓	14.52	22.20	↓	-7.69	14.52	22.20
Steady State		2.250	X	-7.78	-3.21	27.56	23.84	↓	19.78	20.63	↓	-0.85	19.78	20.63
b Cooldown	4.00 hrs	0.315	X	1.78	-4.08	21.32	9.87	↓	23.10	5.79	↓	17.31	23.10	5.79
	4.25	↓	X	1.93	-2.81	↓	↓	↓	23.25	6.06	↓	17.19	23.25	6.06
	4.35	↓	X	2.49	-3.70	↓	↓	↓	23.91	6.17	↓	17.64	23.91	6.17
	4.47	↓	X	2.62	-2.59	↓	↓	↓	23.94	6.98	↓	16.96	23.94	6.98
	5.00	↓	X	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	19.94	↓	-0.41	19.43	19.94
	225 sec	2.275	↓	↓	↓	27.65	24.02	↓	19.87	20.91	↓	-0.94	19.87	20.91

DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs

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	40sec	2.320	0	-7.78	-3.21	27.79	24.35	0	20.01	21.14	0	-1.13	20.01	21.14
	10sec	2.260	↓	↓	↓	27.60	23.92	↓	19.92	20.71	↓	-0.79	19.92	20.71
	260sec	2.190	↓	↓	↓	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	↓	↓	↓	27.99	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
	65sec	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	Heatup 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	X	-7.78	-3.21	28.37	25.65	↓	20.59	22.44	↓	-1.85	20.59	22.44
	Cooldown 3.5 hrs	0.315	X	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	12sec	2.250	"	↓	↓	27.56	23.84	↓	19.78	20.63	↓	-0.85	19.78	20.63
m	16sec	2.760	↓	↓	↓	29.21	27.53	↓	21.43	24.32	↓	-2.89	21.43	24.32
	25sec	2.170	↓	↓	↓	27.14	22.90	↓	19.36	19.69	↓	-0.33	19.36	19.69
	160sec	1.990	↓	↓	↓	24.95	19.99	↓	17.17	16.78	↓	0.39	17.17	16.78
n	33sec	1.300	↓	↓	↓	21.27	9.76	↓	13.49	6.55	↓	6.94	13.49	6.55
	54sec	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

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 84

SHEET 98 OF 51

DATE 5-12-66 BY Cockrell

CHECK DATE 5-12-66 BY [illegible]

5-Detailed Analysis:

e. 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 [illegible] psi		2500	53.29	0	53.29	29.61	0	29.61	57.80	0	57.80	22.10	0	22.10
a [illegible]	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	58.85	32.81	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	0.59	48.84	31.03	1.88	32.91	58.85	-1.51	57.34	20.43	3.98	24.41
b Cool down	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	↓	-8.77	33.25	↓	-30.78	36.21	↓	13.93	26.47
	4.35	↓	↓	-3.83	28.65	↓	-8.35	33.67	↓	-30.68	36.31	↓	13.50	26.04
	4.47	↓	↓	-4.63	27.85	↓	-8.70	33.32	↓	-31.22	35.77	↓	17.89	25.43
	5.00	↓	↓	-8.34	24.14	↓	-6.85	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	59.85	-1.51	57.34	20.43	3.98	24.41
d	20 min	2.250	48.25	↓	48.94	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	↓	23.68
	225 sec	2.275	48.46	↓	49.05	30.88	↓	32.76	50.74	↓	57.23	20.60	↓	24.58

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

DESCRIPTION Fatigue Evaluation of Head Flange Vessel Flange and Closure Studs

NUMBER 5-151-P | A35

SHEET 34 **OF** 51

DATE 5-12-66 **BY** [illegible]

CHECK DATE 5-12-66 **BY** [illegible]

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	49.92	30.63	1.88	32.51	58.55	-1.51	57.04	20.90	3.98	24.88
	16.35sec	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
	12.4 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	26.65	0	26.05	55.17	0	55.17	26.27	0	26.27
j	Heatup 3.5hrs	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 3.5hrs	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	29.13	↓	30.01	56.70	↓	55.19	23.84	↓	27.82
	26sec	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 ksi < 110.2 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 5-51-P | A86
SHEET 35 OF 51
DATE 5-12-66 BY [illegible]
CHECK DATE 5-12-66 BY [illegible]

5. DETAILED ANALYSIS:

c. 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:

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

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

$$\sigma_\theta = \pm \frac{\gamma t_1}{t_1^2}(M_1 + M_{T1})K_B + \nu \frac{H_1 \cos\theta}{t_1} + \frac{E\Delta_{11} + E\delta_{11}}{R_1 \sin\theta} \pm \frac{t_1 \cos\theta (E\Delta_{11}'' + E\delta_{11}'')}{2R_1 \sin\theta} + \frac{a_1^2 P}{7R_1 t_1} + \frac{E\alpha}{(1-\nu)}(T_{m1} - T) - E\alpha(T_{m1} - 70)$$

$$= \pm 0.02035(M_1 + M_{T1})K_B + 0.01096 H_1 + 0.01189(E\Delta_{11} + E\delta_{11}) \pm 0.01922(E\Delta_{11}'' + E\delta_{11}'') + 4.3709 P + 1.42857(T_{m1} - T) - E\alpha(T_{m1} - 70)$$

POINTS 3 & 4:

$$\sigma_x = \pm \frac{6}{t_2^2}(M_3 + M_{T3})K_B + \frac{b^2 P}{2R_2 t_2} K_T + \frac{E\alpha}{(1-\nu)}(T_{m4} - T)K_T$$

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

$$\sigma_\theta = \pm \frac{\gamma t_2}{t_2^2}(M_3 + M_{T3})K_B + \frac{E M_{T3}}{2R_2 P_2 t_2} + \frac{E\Delta_{43}}{R_2} + \frac{bP}{t_2} + \frac{E\alpha}{(1-\nu)}(T_{m4} - T)$$

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

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:

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

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:

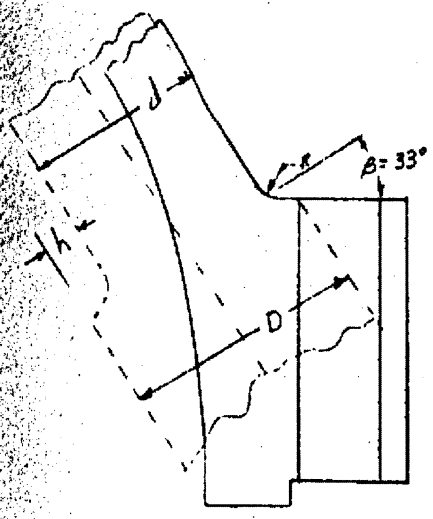
2. CONCENTRATED:

DETERMINATION OF STRESS CONCENTRATION FACTORS:

POINT-1

$K_T = K_B = 1$

POINT-2



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

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

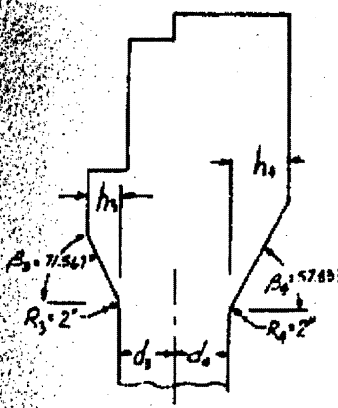
NUMBER 5-151-P | A 98
SHEET 27 OF 51
DATE 5-12-66 BY COCKRELL
CHECK DATE 5-12-66 BY ALEXANDER

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)

5. Detailed Analysis:

a - Stresses:

2. Concentrated:

Location - 1

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	-21.50	-2.51	0	-21.50	-2.51	0	-19.99	-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	3.67
a Heatup	4.00 hrs.	1.932	X	-17.50	-26.03	-14.35	4.02	-1.83	-31.85	-22.61	-1.89	-9.24	-29.97	-20.73
	4.25	2.078		-19.38	-27.93	-13.60	4.70	-2.09	-31.98	-23.29	-2.09	-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	-14.88
Steady State		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 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
	4.15	↓		16.29	25.49	↓	↓	↓	-4.01	24.07	-0.32	-29.08	-3.69	24.39
	4.35	↓		16.43	25.74	↓	↓	↓	-3.07	24.32	-0.32	-28.19	-3.55	24.64
	4.47	↓		16.90	25.89	↓	↓	↓	-3.50	24.47	-0.32	-27.97	-3.18	24.79
	5.00	↓		11.69	19.66	↓	↓	↓	-9.61	18.24	-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	-18.93	-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	-18.87	-11.29	7.59

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 90
SHEET 39 OF 51
DATE 5-12-66 BY [illegible]
CHECK DATE 5-17-66 BY Alexander

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

LOCATION - 1

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	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	40 sec	2.320	-9.3	-4.09	-3.45	-12.68	5.54	-2.32	-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	-2.26	-18.22	0.66	-2.26	-18.96	-15.96	2.92
	260 sec	2.140	-1.3	-1.63	-0.99	-13.37	4.92	-2.14	-15.00	3.93	-2.14	-18.93	-12.86	6.07
g	2 min	2.370	-12.0	-4.92	-4.28	-12.49	5.71	-2.37	-17.41	1.43	-2.37	-18.84	-15.04	3.80
	3.2 min	2.350	-15.0	-5.84	-5.20	-12.57	5.64	-2.35	-18.41	0.44	-2.35	-18.85	-16.06	2.79
	11.4 min	2.150	0	-1.23	-0.59	-13.33	4.95	-2.15	-14.56	4.36	-2.15	-18.92	-12.41	6.51
h	10 sec	2.220	-9.5	-4.15	-3.51	-13.06	5.19	-2.22	-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	-1.91	-12.86	6.14	-1.91	-19.00	-10.95	8.05
i	220 min	3.125	0	0	0	-9.62	8.33	-3.13	-9.62	8.33	-3.13	-17.95	-6.49	11.46
j	Heatup 3.5 hrs	1.250	X	-18.61	-20.73	-16.75	1.83	-1.25	-35.36	-26.90	-1.25	-8.46	-34.11	-25.65
	S.S.	2.500	X	-1.23	-0.59	-11.99	6.17	-2.50	-13.22	5.58	-2.50	-18.80	-10.72	8.08
	Cooldown 3.5 hrs	0.315	X	16.80	25.89	-20.30	-1.42	-0.32	-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	-2.35	-11.96	6.89	-2.35	-18.85	-9.16	9.24
	~	2.150	-6.0	-3.07	-2.43	-13.33	4.95	-2.15	-16.40	2.52	-2.15	-18.92	-14.25	4.67
l	12 sec	2.250	33.3	9.00	9.64	-12.95	5.30	-2.25	-3.95	14.94	-2.25	-18.89	-1.70	17.19
m	10 sec	2.760	-30.2	-10.51	-9.87	-11.01	7.07	-2.76	-21.52	-2.90	-2.76	-18.72	-18.76	-0.04
	29 sec	2.120	-41.2	-13.88	-13.24	-13.44	4.85	-2.12	-27.32	-9.39	-2.12	-18.93	-25.20	-6.27
	160 sec	1.440	4.8	0.24	0.88	-16.03	2.49	-1.44	-15.79	3.37	-1.44	-19.16	-14.35	4.81
n	33 sec	0.300	117	34.71	35.35	-20.36	-1.47	-0.30	14.35	33.88	-0.30	-19.53	14.65	34.18
	54 sec	0.700	197	59.28	59.92	-18.84	-0.08	-0.70	40.44	59.84	-0.70	-19.40	41.14	60.54

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
CHECK DATE 5-12-66 BY Alexander

DESCRIPTION Fatigue Evaluation of Head Flange Vessel Flange and Closure Studs

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	1.822	X	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		47.29	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		-18.82	-5.72	41.65	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
	4.35			-19.87	-6.08				21.58	13.38		8.20	21.58	13.38
	4.47			-20.81	-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.

CHARGE NO. ______

DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs

NUMBER 5-151-P | A 92
SHEET 41 OF 51
DATE 5-12-66 BY [illegible]
CHECK DATE 5-12-66 BY [illegible]

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

Location – 2

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	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	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	28.84
	10.4 min	2.150				57.88	27.05		59.33	27.53		32.00	59.53	27.53
h	10 sec	2.220				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	Heatup 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	X	1.65	0.48	61.01	28.50		62.66	28.98		33.69	62.66	28.98
	Cooldown 3.5 hrs	0.315	X	-20.61	-6.46	41.45	19.46		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	12 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	2.120				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	[illegible]
n	33 sec	0.300				41.32	19.40		42.97	19.88		23.09	42.97	19.99
	54 sec	0.700				44.90	21.06		46.55	21.54		25.01	46.55	21.54

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

CHARGE NO. ______

DESCRIPTION Fatigue Evaluation of Head Flange Vessel Flange and Closure Studs

NUMBER 5-151-P | A93
SHEET 42 OF 31
DATE 5-12-66 BY Cockrell
CHECK DATE 5-12-66 BY Alexander

5. Detailed Analysis:

e. Stresses:

2. Concentrated:

Location -3

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	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		-6.54	-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	13.99	-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	2.110	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	15.25

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

CHARGE NO. ____

NUMBER 5-151-P | A 94
SHEET 43 OF 51
DATE 5-12-66 BY Campbell
CHECK DATE 5-12-66 BY Allinder

DESCRIPTION Fatigue Evaluation of Head Flange Vessel Flange and Closure Studs

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

Location – 5

Transient		Linear Result L/A	$(T_m - T)$ °F	Thermal Stress σ_z	Thermal Stress σ_θ	Pressure Stress σ_z	Pressure Stress σ_θ	Pressure Stress σ_r	Peak Stress σ_z	Peak Stress σ_θ	Peak Stress σ_r	Stress Intensity $\sigma_z-\sigma_\theta$	Stress Intensity $\sigma_z-\sigma_r$	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	-13.5	1.69	-6.59	-12.33	11.02	-2.26	-10.64	4.44	-2.26	-15.08	-9.39	6.70
	260 sec	2.140	-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	8.37	-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	12.33	-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
	165 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	62.98	-0.30	-11.45	51.83	[illegible]3.28
	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.[illegible]4

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 95
SHEET 44 OF 51
DATE 5-12-66 BY [illegible]
CHECK DATE 5-11-66 BY Alexander

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 $\sigma_\theta - \sigma_r$
Cold Bolt up		0	0	0	0	27.10	9.63	0	27.10	9.63	0	17.47	27.10	9.63
Bolt up & 2500 psia		2.5	0	0	0	39.55	27.56	↓	39.55	27.56	↓	11.99	39.55	27.56
a Heatup	4.00 hrs.	1.822	X	-7.25	-0.56	36.48	23.13	↓	29.23	22.57	↓	6.66	29.23	22.57
	4.15	2.078	X	-7.31	-0.57	37.45	24.54	↓	30.14	23.97	↓	6.17	30.14	23.97
	4.35	2.156	X	-7.55	-0.34	37.84	15.47	↓	30.29	24.25	↓	6.04	30.29	24.25
	4.47	2.250	X	-9.14	-0.62	38.31	25.77	↓	29.17	25.15	↓	4.02	29.17	25.15
	5.00	2.250	X	-14.63	-4.26	38.31	25.77	↓	23.68	21.51	↓	2.17	23.69	21.51
Steady State		2.250	X	-10.26	-4.05	38.31	25.77	↓	28.05	21.72	↓	6.33	28.05	21.72
b Cooldown	4.00 hrs.	0.315	X	-0.66	-2.46	28.67	11.89	↓	28.01	9.43	↓	18.59	28.01	9.43
	4.15	↓	X	-0.55	-2.14	↓	↓	↓	29.12	9.75	↓	18.37	29.12	9.75
	4.35	↓	X	0.21	-1.94	↓	↓	↓	28.88	9.91	↓	19.97	28.88	9.91
	4.47	↓	X	0.45	-1.19	↓	↓	↓	29.12	10.70	↓	18.42	29.12	10.70
	5.00	↓	X	4.90	1.48	↓	↓	↓	33.47	13.37	↓	20.10	33.47	13.37
c	20 min	2.250	0	-10.26	-4.05	38.31	25.77	↓	28.05	21.72	↓	6.33	28.05	21.72
d	20 min	2.250	↓	↓	↓	38.31	25.77	↓	28.05	21.72	↓	6.33	28.05	21.72
e	100 sec	2.110	↓	↓	↓	37.76	24.98	↓	27.50	20.93	↓	6.57	27.50	20.93
	225 sec	2.275	↓	↓	↓	38.43	25.95	↓	29.17	21.90	↓	6.27	28.17	2190

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-96*
SHEET *45* OF *51*
DATE *5-12-66* BY [illegible]
CHECK DATE *5-12-66* BY [illegible]

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	220 min	3.125	↓	0	0	42.67	32.05	↓	42.67	32.05	↓	10.62	42.67	32.05
j	Heatup 3.5 hrs	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	X	-10.26	-4.05	39.55	27.56	↓	29.29	23.51	↓	5.78	29.29	23.51
	Cooldown 3.5 hrs	0.315	X	0.45	-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	27.55	21.00
ℓ	13sec	2.350	↓	↓	↓	38.31	25.77	↓	29.05	21.72	↓	6.33	28.05	21.72
m	18sec	2.760	↓	↓	↓	40.65	29.43	↓	30.59	25.38	↓	5.21	30.59	25.38
	29sec	2.130	↓	↓	↓	37.66	26.84	↓	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: Schreell
CHECK DATE 5-12-66 BY: Lee Limoni

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

Transient		Location 5	Location 6	Location 7	Location 8
		σ_r	σ_r	σ_r	σ_r
Cold Cond. Jn		119.64	175.24	273.24	21.64
Start-up + 2500 #		201.16	119.44	231.20	23.40
a	4.20 hrs	135.04	179.20	367.16	-6.72
	4.25 hrs	197.20	168.36	364.34	0.72
	4.35	202.36	164.64	363.40	3.56
	4.47	203.56	164.56	366.64	1.48
	5.00	217.12	161.48	360.68	17.92
Steady State		195.36	131.64	229.36	97.64
b	4.20 hrs	120.68	136.44	151.52	105.72
	4.25	117.60	133.00	144.84	105.99
	4.35	114.60	134.68	145.24	104.16
	4.47	111.40	133.28	143.08	101.72
	5.00	96.56	140.68	152.92	94.44
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
	225 sec	196.20	131.04	229.92	94.32

Transient		Location 5	Location 6	Location 7	Location 8
		σ_r	σ_r	σ_r	σ_r
f	40 sec	197.68	130.64	229.16	99.52
	80 sec	195.72	131.40	229.20	97.92
	240 sec	191.80	134.12	231.20	94.72
g	5 min	199.28	129.39	227.32	100.84
	3.2 min	192.64	129.36	227.63	100.32
	10.4 min	192.12	133.39	231.04	94.96
h	10 sec	192.80	132.32	229.54	96.84
	65 sec	194.29	129.36	225.08	99.56
i	220 min	221.56	124.20	220.53	105.09
j	Heatup 3.5 hrs	170.96	157.24	383.48	-26.00
	S.S.	232.52	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	134.56	[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	144.94	166.30	255.44	56.24

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

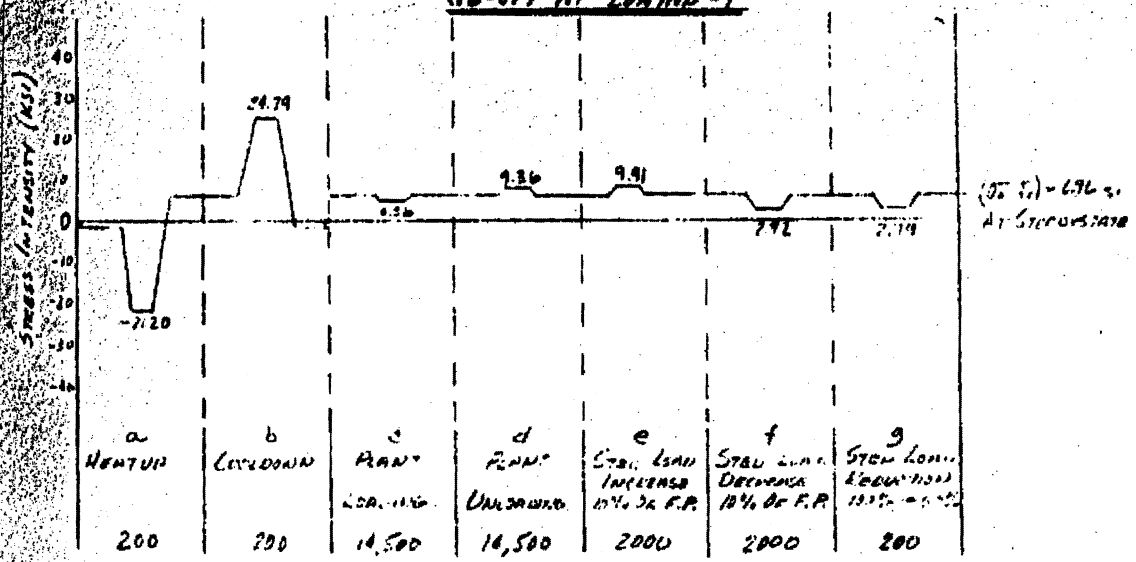
NUMBER S-151-P | A98
SHEET 47 OF 51
DATE 5-12-66 BY [illegible]
CHECK DATE 5-12-66 BY [illegible]

DESCRIPTION FATIGUE EVALUATION OF HEAD FLANGE VESSEL FLANGE AND CLOSURE STUDS

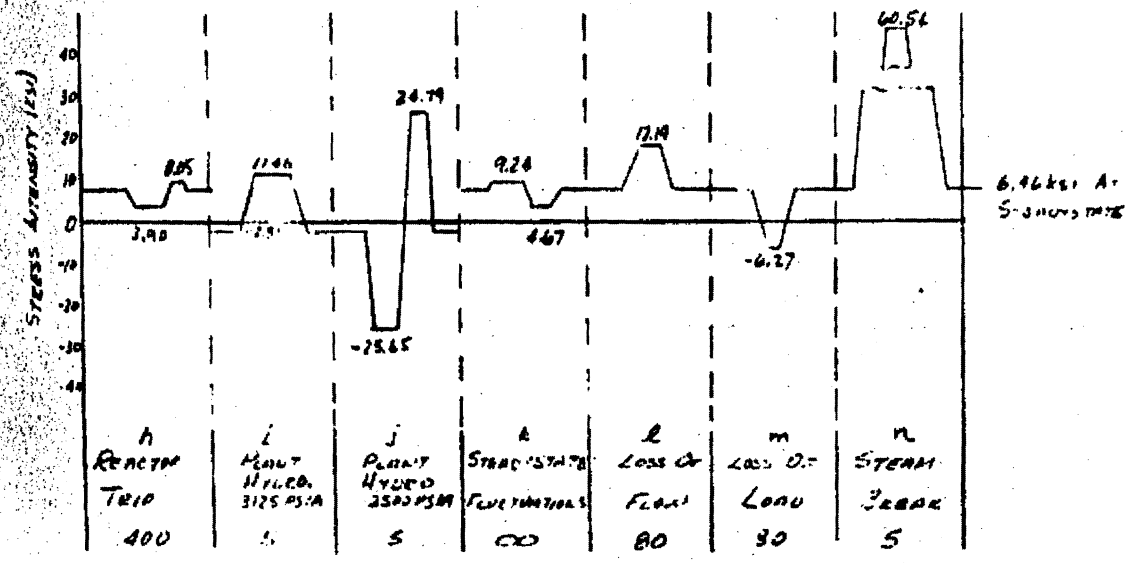
5. DETAILED ANALYSIS:

f. FATIGUE EVALUATION:

$(S_o - S_r)$ AT LOCATION - 1



a	b	c	d	e	f	g
HEATUP	COOLDOWN	PLANT LOADING	PLANT UNLOADING	STEP LOAD INCREASE 10% OF F.P.	STEP LOAD DECREASE 10% OF F.P.	STEP LOAD REDUCTION 10% OF F.P.
200	200	14,500	14,500	2000	2000	200



h	i	j	k	l	m	n
REACTOR TRIP	MAIN FEED. 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^a	U
40.54	-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

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

$U_{OVERALL}$ = 0.00423

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

CHARGE NO. _____

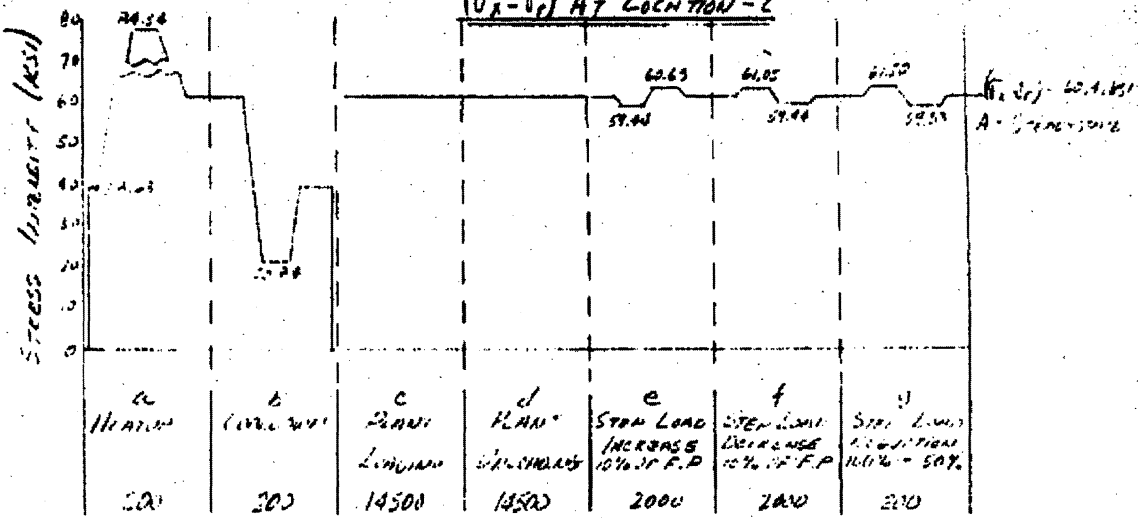
DESCRIPTION Fatigue Evaluation Of Head Flange Vessel Flange And Closure Studs

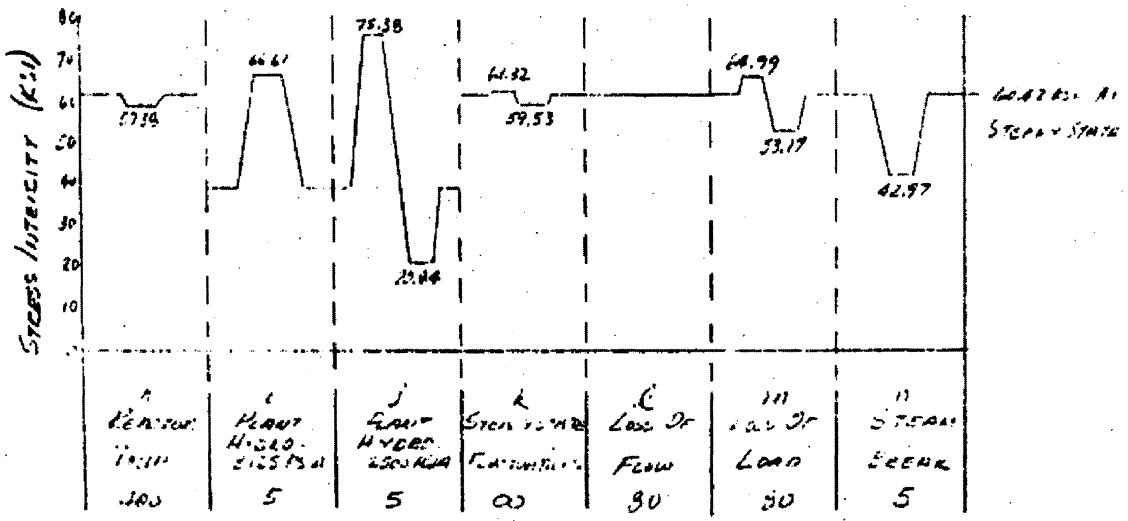
NUMBER S-151-P | L 99
SHEET 48 OF 51
DATE 5-12-66 BY Correll
CHECK DATE 5-12-66 BY Fleshader

5. Detailed Analysis:

1. Fatigue Evaluation:

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





S_{max}	S_{min}	Number Of Occurrences	S_{alt}	N^*	U
74.34	0	40	42.2	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