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LOFT PRIMARY SYSTEM SMALL USAGE PRESSURE CYCLE

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APPLIED MECHANICS BRANCH

LOFT PRIMARY SYSTEM SMALL USAGE PRESSURE CYCLE

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August 11, 1977ABSTRACT

Basis, definition, and determination of the LOFT primary system minor primary pressurization cycle is presented. Example pressure-time plots are given which illustrate recognition of the minor primary pressurization cycle during typical plant operations.

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1.0 INTRODUCTION

This report describes bases, definition, and the method to be used for determination of LOFT primary system minor pressurization cycles.

A primary coolant system minor pressurization cycle is defined as being the maximum pressure fluctuation within the LOFT primary coolant system for which insignificant fatigue damage usage factor ($\Delta U < 1$) is accumulated in the LOFT primary system pressure boundary for a large number of such pressure fluctuation cycles ($N > 10^6$ cycles). Associated with this maximum range of pressure is a primary coolant temperature range limit of $\pm 20^\circ\text{F}$ such that associated thermal stresses are insignificant⁽¹⁾. A cycle, during which these parameters are equal to or less than the given maximum values, is termed a minor primary pressurization cycle and need not be counted.

2.0 CYCLE DEFINITION

A "cycle" may be defined by those parameters ($p(t)$ and $T_f(t)$) that change between identical bounding states of the system where $p(t)$ and $T_f(t)$ are coolant pressure and temperature, respectively, as a function of time, t . For example, if $p(t_0)$ and $T_f(t_0)$ describe the system at time t_0 and a later state is defined by $p(t_1)$ and $T_f(t_1)$, then $p(t)$ and $T_f(t)$, $t_0 \leq t \leq t_1$, describe a cycle if $p(t_1) = p(t_0)$ and $T_f(t_1) = T_f(t_0)$. This is illustrated in Fig. 1. Thus, the definition of a cycle is independent of the magnitude of the initial and final pressure and temperature. Rather, the requirement is that the initial and final pressures and temperatures be the same.

3.0 QUALIFICATION OF PRESENT PROCEDURE

The ASME Boiler and Pressure Vessel Code⁽²⁾ describes the method by which cycles and their associated fatigue damage usage factors are calculated.

Fig. 1

Illustration of Cycle Definition

The procedure is based on the maximum stress range that occurs in the pressure boundary during a cycle. The stress range is dependent on the pressure range and coolant temperature range with associated temperature gradients formed within the pressure boundary during a cycle. Thus, if the primary coolant temperature range is assumed small ($\Delta T_f \leq |\pm 20^\circ\text{F}|$), then the only variable that affects the stress range is pressure range.

In the LOFT primary coolant system pressure boundary, the component that experiences the largest stress range for a given pressure change is the steam generator tubesheet. The Appendix of this report contains the method and calculations which determine the maximum range of pressure fluctuation such that a cycle may be classified as a minor primary pressurization cycle. This procedure is based on construction of a Goodman Diagram which is a function of mean stress as well as alternating stress. Thus, the maximum primary pressure fluctuation range, Δp_a , is a function of the mean differential pressure on the tubesheet, Δp_m .

Figure 2 illustrates the results of the appended calculations. It is noted that the maximum primary pressure fluctuation range is $\Delta p_a = 480$ psi for the mean differential pressure on the tubesheet, Δp_m , equal to or less than 860 psi. Also, note that $0 \leq \Delta p_a \leq 480$ psi for $860 \text{ psi} \leq \Delta p_m \leq 1340$ psi. Figure 3 illustrates these results in the form of primary and secondary pressure vs. time plots.

4.0 EXAMPLES OF MINOR PRIMARY PRESSURIZATION CYCLE

Figure 4 illustrates the bounding differential pressure ranges associated with a minor primary pressurization cycle that may occur during typical plant operations.

It is noted that the minor pressurization cycle may be repeated during

Fig. 2

Maximum Alternating Differential Pressure
as a Function of Mean Differential Pressure

Fig. 3

Illustration of Minor Pressurization Cycle

a. Plant Heatup

b. Hot Standby

c. Plant Cooldown

Fig. 4
Examples of Minor Pressurization
Cycle During Plant Operation

the operations shown in Fig. 4 or may be superimposed on other plant operational cycles in a similar manner.

5.0 REFERENCES

1. N. E. Pace, "Thermal Cycle Counting for the LOFT Primary Coolant System", LTR 114-84, RE-E-77-039, July 13, 1977.
2. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, 1977.
3. J. J. Candors, "LOFT Steam Generator Stress and Fatigue Life Report", LTR 1141-20, TR-807, April 23, 1976.
4. S. Timoshenko, Strength of Materials, Part II, D. Van Nostrand, Inc, 1941.
5. R. C. Juvinall, Stress, Strain and Strength, McGraw-Hill, 1967.

APPENDIX: LOFT STEAM GENERATOR MINOR
PRESSURIZATION CYCLE CALCULATIONS

CALCULATION OF ALLOWABLE RANDOM PRESSURE VARIATION IN LOFT STEAM GENERATOR

THE PRESSURIZATION OR DEPRESSURIZATION OF THE LOFT STEAM GENERATOR MAY NOT PROCEED SMOOTHLY BUT CAN BE ASSOCIATED WITH CERTAIN RANDOM PRESSURE VARIATION. IT IS OF INTEREST TO DETERMINE THE LIMITS OF THIS RANDOM PRESSURE VARIATION WHICH COULD BE APPLIED TO THE STEAM GENERATOR UNLIMITED NUMBER OF TIMES WITHOUT DETRIMENTAL EFFECT TO THE STEAM GENERATOR STRUCTURE.

THE SITUATION FOR WHICH THE ANALYSIS IS INTENDED IS SHOWN IN FIGURE 1. BELOW:

FIGURE 1.

THE THEORETICAL PRESSURE INCREASING OR DECREASING AT A CONSTANT RATE IS INDICATED BY P_m AND IS SHOWN AS A FUNCTION OF TIME. THE DEVIATION FROM

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STRAIGHT LINE INCREASE, DECREASE OR CONSTANT PRESSURE, AT THE SAME TIME WHEN P_m IS MEASURED, IS DESIGNATED BY P_a .

THE ANALYSIS WAS STARTED BY FINDING A LOCATION IN THE STEAM GENERATOR WHICH IS MOST CRITICALLY AFFECTED BY PRESSURE FLUCTUATION. REFERENCE (3) SHOWED THAT SUCH A LOCATION IS STEAM GENERATOR TUBESHEET PERFORATIONS.

NEXT STEP WAS TO CONSTRUCT A MODIFIED GOODMAN'S DIAGRAM AS SHOWN IN FIGURE 2. TO CONSTRUCT THE GOODMAN'S LINE (A-B IN FIGURE 2.) A VALUE OF ENDURANCE LIMIT (S_N) WAS REQUIRED WHICH WAS NOT AVAILABLE FOR THE TUBESHEET MATERIAL (SA-105, GR II CARBON STEEL FORGING). HOWEVER, TIMOSHENKO (REF. 4) PROPOSES THAT AS A ROUGH ESTIMATE IN THE CASE OF FERROUS MATERIALS THE ENDURANCE LIMIT FOR REVERSAL OF STRESSES CAN BE TAKEN EQUAL TO 0.40 TO 0.50 OF ULTIMATE STRENGTH. TAKING THE ULTIMATE STRENGTH OF SA-105, GR II AT 600°F AS 51,720. PSI THE LOWER ENDURANCE LIMIT IS:

$$S_N = (51,720.) (.40) = 20,680. \text{ PSI}$$

WITH THE ABOVE ENDURANCE LIMIT OF 20,680.PSI THE GOODMAN'S LINE AB WAS CONSTRUCTED AS SHOWN IN FIGURE 2. THE GOODMAN'S DIAGRAM WAS MODIFIED BY THE YIELD LINE C-D.

ALL POINTS BELOW AED IN FIGURE (2) NOW CORRESPOND TO FLUCTUATING STRESSES WHICH COULD CAUSE NEITHER FATIGUE FRACTURE NOR PLASTIC DEFORMATION. IT MUST BE NOTED THAT IN GOODMAN'S DIAGRAM THE ALLOWABLE FLUCTUATING STRESSES ARE A FUNCTION OF MEAN STRESSES OVER WHICH THE FLUCTUATING STRESSES ARE SUPERIMPOSED.

HOW DOES THIS AGREE WITH SECTION III OF BOILER AND PRESSURE VESSEL CODE REQUIREMENTS ?

SECTION III (REF. 2) IN FIGURE I-9-1 SHOWS A FATIGUE CURVE FOR CARBON AND LOW ALLOY STEELS.

THIS CURVE EXTRAPOLATED TO ABOUT $(10)^7$ CYCLES BECOMES APPARENTLY ASYMPTOTIC TO THE $S_0 = (10)^4$ PSI LINE INDICATING THE ENDURANCE LIMIT AT $S_a = (10)^4$ PSI. THAT THE ENDURANCE LIMIT IS AT $(10)^7$ CYCLES IS IN AGREEMENT WITH R.C. JUVNALL WHO OBSERVED (REF. 5) THAT IN STEELS THE ENDURANCE LIMIT IS REACHED IN BETWEEN $(10)^6$ TO $(10)^7$ CYCLES. IT IS EVIDENT THAT THE ALTERNATING STRESS (S_a).

CONSIDERABLY MORE CONSERVATIVE IN SECTION III THAN IN GOODMAN'S DIAGRAM. IN ORDER TO SATISFY THE SECTION III REQUIREMENTS, THE GOODMAN'S DIAGRAM WAS MODIFIED ONCE MORE BY INTRODUCING THE $(10)^7$ LINE GF (FIGURE 2.). ALL POINTS BELOW THE GFD IN FIGURE 2. CORRESPOND TO FLUCTUATING STRESSES WHICH COULD CAUSE NEITHER FRACTURE NOR PLASTIC DEFORMATION AND SATISFIES SECTION III.

FIGURE 2 SHOWS THAT THE ALLOWABLE FLUCTUATING STRESSES STAY CONSTANT (± 10000 PSI) UNTIL THE MEAN STRESSES REACH ABOUT 16500 PSI AND THEN DROP SHARPLY. WHEN THE MEAN STRESS REACH YIELD STRESSES NO FLUCTUATING STRESSES ARE ALLOWED TO BE SUPERIMPOSED.

TO FAR NO CONSIDERATION WAS GIVEN TO THE ACTUAL STRUCTURE AND DIAGRAM IN FIGURE 2. WAS CONSTRUCTED BASED ON MATERIAL PROPERTIES ONLY. IN ORDER TO CALCULATE THE ALLOWABLE FLUCTUATING PRESSURE THE ACTUAL STRUCTURE MUST BE CONSIDERED. AS IT WAS MENTIONED BEFORE, THE AREA MOST SENSITIVE TO PRESSURE FLUCTUATIONS IS IN THE STEAM GENERATOR TUBE SHEET PERFORATIONS. WHAT IN ESSENCE IS NEEDED IS TO CONSTRUCT A DIAGRAM SIMILAR

TO THE ONE IN FIGURE 2, BUT IN TERMS OF PRESSURES INSTEAD OF STRESSES AS SHOWN IN FIGURE 3.

THE YIELD PRESSURE LINE C-D IN FIGURE 3 WAS FOUND AS FOLLOWS:

THE TUBESHEET SURFACE STRESSES IN FIGURE A-19 (REF. 1) ARE GIVEN FOR ELEMENT 557 AS:

$$\sigma_R = 6800 \text{ PSI}$$

$$\sigma_T = 5620 \text{ PSI}$$

$$\text{DUE TO } \Delta p = 1400 \text{ PSI}$$

STRESSES IN THE PERFORATIONS ARE GIVEN BY EXPRESSION (3) IN CHAPTER A-8142.2 (REF. 2) AS:

$$S_\phi = Y_1 \frac{P}{h} \sigma_1 + Y_2 \frac{P}{h} \sigma_2 + P_s \quad \text{----- (1)}$$

REFERENCE (3) ON PAGE A-156 SHOWS THAT THE CRITICAL LOCATION IS AT $\alpha = 15^\circ$ AND $\phi = 105^\circ$ (IT IS IMPOSSIBLE TO GO INTO DETAILS EXPLAINING TERMS IN EXPRESSION (1) IN THIS REPORT AND ONE IS ADVISED TO CONSULT THE PERTINENT SECTIONS IN REFERENCES (1) AND (2))

WITH COEFFICIENTS Y_1 AND Y_2 FROM TABLE A-37 (REF 1.)

$$S_\phi = \frac{.75}{.244} [1.76(6800) + (-.52)(5620)] = 27,804 \text{ PSI}$$

SINCE WE ARE DEALING WITH A LINEAR ELASTICITY PROBLEM, THE ΔP PRESSURE CORRESPONDING TO $S_y = 26,600$ PSI (YIELD STRESS) WAS FOUND AS FOLLOWS:

$$P_{\sigma=\sigma_y} = (1400) \frac{26,600}{27,804} = 1339.4 \sim 1340 \text{ PSI}$$

SIMILARLY THE LINE GF, CORRESPONDING TO THE ALTERNATING PRESSURE AS LIMITED BY SECTION III, WAS ALSO OBTAINED. NOTING THAT THE CORRESPONDING ALTERNATING STRESSES (FIGURE 2) IN TUBESHEET PERFORATIONS ARE $(10)^4$ PSI.

$$P_{\sigma=(10)^4} = (1400) \frac{10,000}{27,804} = 503 \text{ PSI} \sim 500 \text{ PSI}$$

BEFORE ACCEPTING THE 500 PSI ALTERNATING PRESSURE AS THE LIMITING SECTION III PRESSURE THE EFFECT OF THIS LOADING IN CUMULATIVE DAMAGE WAS INVESTIGATED, NAMELY, IF STRESSES DUE TO ΔP LOADING ACROSS THE TUBESHEET PRODUCING $S_a = 10,000$ PSI IN TUBESHEET PERFORATIONS, CONSIDERED AS A SEPARATE TRANSIENT, WOULD COMBINE WITH SOME OTHER TRANSIENT GIVING $S_a > (10)^4$ PSI.

THIS INVESTIGATION RESULTED IN REDUCTION OF ΔP FROM 500 PSI TO 480 PSI (ELEMENT 13, PARTIAL MODEL OF UPSTREAM FILLET, REF. 3)

THE ALLOWABLE ALTERNATING PRESSURE DIFFERENCE, ΔP_a , WHICH CAN BE SUPERIMPOSED TO A MEAN PRESSURE DIFFERENCE ΔP_m ACROSS THE TUBESHEET IS SHOWN IN FIGURE 3 BY LINE GFD.

IT WAS ASSUMED THAT NO THERMAL STRESSES ACT SIMULTANEOUSLY WITH THE STRESSES DUE TO PRESSURE.

FIGURE 3

ALLOWABLE ALTERNATING PRESSURE
VS MEAN PRESSURE.

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