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STRESS ANALYSIS OF ULTRASONIC DENSITY DETECTOR
FOR LOFT CORE INLET STEADY-STATE AND LOCE CONDITIONS

W. R. Mosby

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**LOFT TECHNICAL REPORT
LOFT PROGRAM**

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ABSTRACT

The UDD sensor bar with modified cross-section (0.0938-inch thick by 0.25-inch high overall) was analyzed to determine its resonant frequencies. Thermal and fluid-induced stresses due to steady-state and LOCE loads were also calculated. The sensor bar was shown not to be subject to vortex-shedding lock-in and was shown to meet applicable criteria of the ASME Boiler and Pressure Vessel Code.

Seismic loads are insignificant compared to fluid loads.

DISPOSITION OF RECOMMENDATIONS

No disposition required.

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STRESS ANALYSIS OF ULTRASONIC DENSITY DETECTOR FOR LOFT CORE INLET STEADY-STATE AND LOCE CONDITIONS

I. SCOPE OF INVESTIGATION

The UDD sensor bar with modified cross-section was analyzed to determine its resonant frequencies. Thermal and fluid-induced stresses due to steady-state and LOCE loads were also calculated.

II. METHOD OF ANALYSIS

1. SENSOR BAR RESONANT FREQUENCIES

The SAP IV computer model of the sensor bar (Ref. 1) was modified to reflect the changed bar section properties (Ref. 2) and fluid added mass (Ref. 3) and used to calculate the sensor bar resonant frequencies.

2. FLUID-INDUCED STRESSES

The fluid-induced stresses in the bar were calculated from previous results (Ref. 1) and the section properties of the modified sensor bar. All other fluid-induced stresses in the UDD are the same as calculated in Reference 1.

3. THERMAL STRESSES

The modified sensor bar thermal stresses were found to be less than one percent higher than those calculated for the sensor bar of Reference 1 and are below the allowable stresses given in Reference 4. The fatigue limit of 10,400 LOCE's, calculated in Reference 1, still holds for the modified sensor bar. Thermal stresses in the massive termination and mounting screws were found to be slightly lower than those calculated in Reference 1.

III. RESULTS

1. SENSOR BAR RESONANT FREQUENCIES

As shown in Figure 2 and in the Table of the Appendix, all sensor bar resonant frequencies lie well above the vortex-shedding lock-in range.

2. FLUID-INDUCED STRESSES

The sensor bar maximum peak stress intensity due to fluid forces was calculated to be 2920 psi. Primary stresses are less than this, while the allowable stress intensity is 13,700 psi.

3. THERMAL STRESSES

The results of Reference 1 still apply to the UDD with modified sensor bar.

IV. CONCLUSIONS

The UDD with modified sensor bar meets the requirements of Reference 4, NB-3200, and Reference 5 if its curvature and screw torquing or retainers conform to the recommendations of Reference 1.

V. REFERENCES

1. W. R. Mosby, "Stress Analysis of Ultrasonic Density Detector for LOFT Core Inlet Steady-State and LOCE Conditions", LOFT Technical Report LTR 141-86 (to be published).
2. R. J. Roark and W. C. Young, Formulas for Stress and Strain, 5th Edition, McGraw-Hill, 1975.
3. R. Greif and M. Coltman, "Mechanics of Ultrasonic Densitometers", Panametrics, September 30, 1977.
4. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, Division 1, "Nuclear Power Plant Components", 1977.
5. Specification ES-60203, Rev. B, "Density Ultrasonic Detector System for LOFT Core Inlet".

APPENDIX A
UDD SENSOR BAR MOD 4.0

CALCULATION WORK SHEET

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1. Geometry

Figure 1 shows the revised UDD sensor cross-section (referred to here as Mod 4.0). All other sensor dimensions remain the same as given in ref. 1.

Section properties

$$I_{22} = \frac{\pi}{3} \left\{ \int_0^{.0317} \left(\sqrt{(.032)^2 - x^2} + .093 \right)^3 dx + \int_{.0317}^{.04604} \left(\frac{.0985(x - .04604) + .01574(.0317 - x)}{-.01434} \right)^3 dx + \int_{.04604}^{.0469} \left(\sqrt{(.0938)^2 - (x + .0469)^2} \right)^3 dx \right\}$$

$$I_{22} = \underline{\underline{7.62 \times 10^{-5} \text{ in}^4}}$$

Figure 1: UDD Sensor Cross-section

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$$\begin{aligned}
 I_{33} = & \frac{4}{3} \left\{ \int_0^{.01574} \left(\sqrt{(.0938)^2 - x^2} - .0469 \right)^3 dx \right. \\
 & + \int_{.01574}^{.0985} \left(\frac{.04604(x - .0985) + .0317(.01574 - x)}{-.08276} \right)^3 dx \\
 & \left. + \int_{.0985}^{.125} \left(\sqrt{(.032)^2 - (x - .093)^2} \right)^3 dx \right\}
 \end{aligned}$$

$$\underline{\underline{I_{33} = 9.39 \times 10^{-6} \text{ in}^4}}$$

$$\begin{aligned}
 A = & 4 \left\{ \int_0^{.0317} \left(\sqrt{(.032)^2 - x^2} + .093 \right) dx \right. \\
 & + \int_{.0317}^{.04604} \left(\frac{.0985(x - .04604) + .01574(.0317 - x)}{-.01434} \right) dx \\
 & \left. + \int_{.04604}^{.0469} \sqrt{(.0938)^2 - (x + .0469)^2} dx \right\}
 \end{aligned}$$

$$\underline{\underline{A = 1.83 \times 10^{-2} \text{ in}^2}}$$

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From ref. 2, p. 294, Case 19 :

$$J = \frac{4 I_{33}}{1 + 16 I_{33} / A U^2} = \frac{4 (9.39 \times 10^{-6})}{1 + 16 (9.39 \times 10^{-6}) / (.0183)(.25)^2}$$

$$\underline{J = 3.32 \times 10^{-5} \text{ in}^4}$$

2. Sensor bar resonant frequencies

The SAP IV computer model described in ref. 1 was used to calculate the sensor bar resonant frequencies. The following beam element and material properties were used.

a. Beam element properties

(1) type 1 - elements 2-14

$$I_{22} = 7.62 \times 10^{-5} \text{ in}^4$$

$$I_{33} = 9.39 \times 10^{-6} \text{ in}^4$$

$$A = 1.83 \times 10^{-2} \text{ in}^2$$

$$J = 3.32 \times 10^{-5} \text{ in}^4$$

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(2) type 2 - elements 1 and 15

these are unchanged from ref. 1

$$I_{22} = I_{33} = 1.629 \times 10^{-9} \text{ in}^4$$

$$A = .04524 \text{ in}^2$$

$$J = 3.25 \times 10^{-9} \text{ in}^4$$

b. Beam material properties

(1) type 1 - elements 2-14

From ref. 3,

$$\rho = 7.505 \times 10^{-4} - \frac{\pi (8.343 \times 10^{-5})(.125)^2}{1.83 \times 10^{-2}} = \underline{\underline{9.74 \times 10^{-4} \frac{\text{lb} \cdot \text{sec}^2}{\text{in}^4}}}$$

$$\text{where } \rho_{\text{steel}} = .29 \text{ lb/in}^3 = 7.505 \times 10^{-4} \frac{\text{lb} \cdot \text{sec}^2}{\text{in}^4}$$

$$\rho_{\text{H}_2\text{O}} = 1.73 \text{ slug/ft}^3 = 8.343 \times 10^{-5} \frac{\text{lb} \cdot \text{sec}^2}{\text{in}^4}$$

$$E = E_{\text{at } 650^\circ\text{F}} = \underline{\underline{25.1 \times 10^6 \text{ psi}}}$$

$$V = \underline{\underline{.3}}$$

$$w = \underline{\underline{.29 \text{ lb/in}^3}}$$

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(2) type 2-elements 1 and 15

$$\rho = \underline{8.339 \times 10^{-2} \text{ lb} \cdot \text{sec}^2/\text{in}^4}$$

$$E = \underline{25.11 \times 10^6 \text{ psi}}$$

$$\nu = \underline{.3}$$

$$w = \underline{.29 \text{ lb/in}^3}$$

c. Calculated frequencies

The Table gives sensor bar resonant frequencies as a function of sensor bar curvature.

TABLE

UDD Sensor Bar Resonant Frequencies in water
 at 650 °F, hz.

Mode Curvature	Sym. X-Y	Asym. X-Y	Sym. Z
0	2450	3407	3281
1/8	3723	3287	3094
1/4	5092	3122	2769
3/8	5840	2924	2448

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Resonant Freqs for MOD 4.0
 Sensor Bar.

Figure 2: Resonant Frequencies vs curvature for VDD Sensor Bar Mod 4.0

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SAP IV Sensor Bar Frequency
Output

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As shown in figure 2, all sensor bar natural frequencies are out of the vortex-shedding lock-in range as calculated in ref. 1. This range is a function of the sensor bar thickness normal to the flow and is thus unchanged from ref. 1.

3. Sensor bar thermal and fluid-induced stresses
 - a. fluid-induced stresses

These stresses will be increased due to the reduction in section:

$$2T_{MAX} \approx 1587 \text{ psi} \left(\frac{c'}{I'} \frac{I}{c} \right)$$

where c' = mod 4.0 sensor half thickness
 c = ref. 1 sensor half-thickness
 I' = mod 4.0 sensor moment of inertia
 I = ref. 1 sensor moment of inertia
 1587 = MAX peak stress (ref. 1)

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For the 2-2 Axis,

$$\left(\frac{C'}{I'} \frac{I}{C} \right) = \frac{.125}{7.62 \times 10^{-5}} \frac{2.1043 \times 10^{-4}}{.1875} = \underline{\underline{1.84}}$$

For the 3-3 Axis,

$$\left(\frac{C'}{I'} \frac{I}{C} \right) = \frac{.0469}{9.39 \times 10^{-6}} \frac{1.3714 \times 10^{-5}}{.0469} = \underline{\underline{1.14}}$$

the maximum fluid induced stress is then

$$\sigma_{TMAX} = 1.84(1587) = 2920 \text{ psi}$$

This is still much less than the allowable stress of $1.5 S_w = 20,550 \text{ psi @ } 650^\circ \text{F}$.

b. thermal stress

The sensor bar thermal stress model used in reference 1 was used to calculate thermal stresses for the Mod 4.0 sensor bar. Thermal stresses were found to increase by less than one percent in the sensor bar.

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The sensor bar stresses calculated in reference 1 are at least 10% below the allowable stress intensity, so the increased stress in the Mod 4.0 sensor bar does not cause a problem. The fatigue life of 10,400 cycles calculated in reference 1 is still correct.

Thermally-induced forces and moments in the sensor bar massive terminations and mounting screws decreased slightly, so the corresponding stress calculations in reference 1 still apply.

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SAP IV Sensor Bar Fluid and
Thermal Stress Output

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