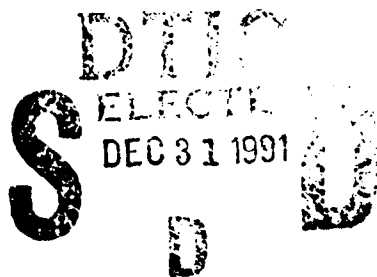


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THESIS

PASSIVE VIBRATION CONTROL OF THICK ALUMINUM
PLATES USING VISCOELASTIC LAYERED DAMPING

by

PING HSIN-CHIH

December, 1990

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PLATES USING VISCOELASTIC LAYERED DAMPING**

by

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CAPTAIN, R.O.C. Taiwan ARMY
B.S., Chung Cheng institute of Technology, 1983

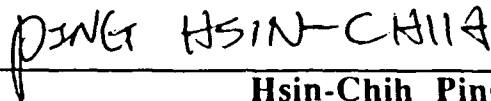
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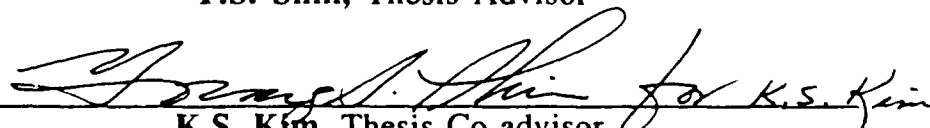
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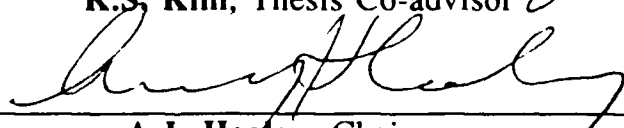
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ABSTRACT

This paper considers two constrained viscoelastic layer damping treatments applied to a thick aluminum plate; a milled pocket, and a milled floating element configurations. The effectiveness of the Modal Strain Energy (MSE) method was investigated for the constrained viscoelastic layer damping design. A comparison of experimentally measured modal loss factors and natural frequencies with those predicted by the modal strain energy method is presented.

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I. INTRODUCTION

A. BACKGROUND

Ship silencing is an important issue of modern naval warfare. For a long time, naval ship engineers have tried to reduce the noise from the vibration of shipboard components. This is important for a ship to accomplish its mission with good survivability. One method, called constrained viscoelastic layer method, uses shear deformation in viscoelastic material to absorb and dissipate the vibrational energy of the system. It shows promise in damping over a broad frequency spectrum of vibration.

A finite element technique developed by Johnson and Kienholz [Ref.1] known as the Modal Strain Energy (MSE) method which uses the ratio of strain energy for each mode shape to approximate the modal damping of a structure for a given constrained viscoelastic damping system. This method is very attractive due to its simple concept and very useful because it can be applied to any general cases with arbitrary shape by using the finite element method. Previous work by Bateman [Ref. 2] addressed the effectiveness of the MSE method for three damped plate configurations: 1) a single layer sandwich configuration, 2) a double layer sandwich configuration, and 3) a plate with a milled pocket with damping material inserted and a spot welded cover plate acting as a constrained layer. Difficulties with the welded cover

plate is that during welding, the cover plate can be warped and delaminated itself from the damping material, resulting in negligible damping [Ref. 3].

B. PURPOSE

Development of the model enhancing the vibration damping, reducing the noise and vibration is the main purpose. This paper will concentrate the experimental testing and analysis of two configurations of aluminum plates: 1) milled pocket plate, a plate with a milled pocket with damping material inserted and a welded cover plate acting as a constraining layer. and 2) floating element plate, like pocket plate but between welded cover plate and milled pocket inserted a floating element that was a thin aluminum plate with two damping material on upper and lower sides. The floating element was made slightly smaller than the surrounding structure thus allowing the floating element to act as a "true" constraining layer. Each plates expose to three different temperatures, 4.44 °C (40 °F), 15.6 °C (60 °F), 26.7 °C (80 °F) to simulate different environment.

The MSE method is used to analyze and predict each of the structures, and compare to experimental results. Its accuracy and usefulness as a possible design tool are investigated.

C. PLATE CONFIGURATIONS

The dimensions of the pocket plate are : base plate 114.30 cm (45 in) in length and 38.1 cm (15 in) in width, viscoelastic material 111.13 cm (43.75 in) in length, 34.93 cm (13.75 in) in width, and 0.038 cm (0.015 in) in thickness, cover plate 113.03 cm (44.5 in) in length, 36.83 cm (14.5 in) in width, and 0.635 cm (0.25 in) in thickness. The total thickness is approximately 1.91 cm (0.75 in).

The dimensions of the floating element plate are: base plate 114.30 (45 in) cm in length and 38.1 (15 in) cm in width, two viscoelastic material 111.13 cm (43.75 in) in length, 34.93 cm (13.75 in) in width, and 0.038 cm (0.015 in) in thickness, the aluminum plate between two viscoelastic material 111.13 cm (43.75 in) in length, 34.93 cm (13.75 in) in width, and 0.3175 cm (0.125 in) in thickness, cover plate 113.03 cm (44.5 in) in length, 36.83 cm (14.5 in) in width, and 0.381 cm (0.015 in) in thickness. The total thickness is approximately 1.91 cm (0.75 in).

The aluminum plate is a standard 6061-T6 aluminum alloy and the viscoelastic material is a polymeric compounds from 3M company type ISD-112.

The details of two plate configurations are shown in Appendix A.

II. THEORY

A. MODAL STRAIN ENERGY METHOD

The equations of motion for the discretized continuous system can be expressed in the following form:

$$[M] \{x(t)\} + [C] \{\dot{x}(t)\} + [K] \{x(t)\} = \{F(t)\} \quad (2-1)$$

where,

$[M]$ = Mass matrix

$[C]$ = Damping matrix

$[K]$ = Stiffness matrix

Introducing linear transformation from physical coordinate system, $\{x(t)\}$ to modal coordinate system, $\{q(t)\}$, into the equation (2-1),

$$\{q(t)\} + [\eta_i \omega_i] \{\dot{q}(t)\} + [\omega_i^2] \{q(t)\} = \{F(t)\} \quad (2-2)$$

$$\{x(t)\} + [\Phi] \{q(t)\} \quad (2-3)$$

$$\{f(t)\} = [\Phi]^T \{F(t)\} \quad (2-4)$$

where $[\eta_i \omega_i]$ and $[\omega_i^2]$ are diagonal matrices. Equation (2-2) is decoupled equations of motion in modal space.

For MSE method, the i -th modal loss factor, η_i in equation (2-2) can be approximated by the following expression,

$$\eta_i = \eta_{v:i} \left(\frac{V_{v:i}}{V_{T:i}} \right) \quad (2-5)$$

where

η_i = i -th modal loss factor

$\eta_{v:i}$ = viscoelastic material loss factor at i -th modal frequency

$V_{v:i}$ = elastic strain energy in viscoelastic layer at i -th modal frequency

$V_{T:i}$ = total strain energy at i -th modal frequency

For this method, modal analysis was used to calculate the fraction of elastic strain energy in the viscoelastic material at each corresponding mode and to calculate modal loss factor defined in equation (2-5).

Because the natural frequency depends on material properties, an iterated solution of the eigenvalue problem for each mode and the material vs. frequency relation is required.

A simple empirical correction allows an approximate correction for frequency-dependent material properties [Ref. 4]. The modal damping ratios are adjusted according to

$$\eta_i^{(r)} = \eta_i^{(r)} \sqrt{\frac{G_2(f_r)}{G_{2,ref}}} \quad (2-6)$$

where,

$\eta_c^{(r)}$ = corrected modal loss factor at the r^{th} mode

$G_2(f_r)$ = viscoelastic shear modulus at the r^{th} modal frequency

$G_{2,ref}$ = reference viscoelastic shear modulus used in the frequency
response calculation

calculation to obtain modal frequency, mode shape, and masses

$G_{2,i}$ = viscoelastic material shear modulus at $f = f_i$ where f_i is the i -
th natural frequency of the i -th mode calculated with $G = G_{2,i,ref}$

In using Modal Strain Energy Method the MSC/NASTRAN code [Ref. 5]
was used to estimate the natural frequency, mode shape, and strain energy.

B. VISCOELASTIC MATERIAL

The long molecular chains of most elastomeric or rubberlike materials have much higher level of damping than is the case of metals. The behavior is usually linear for low strain levels and nonlinear for high, as well as being frequency and temperature dependent.

Viscoelastic material is one kind of elastomeric material. In this paper we use 3M company ISD-112 viscoelastic material as damping treatment material. The advantage of the viscoelastic material is its ability to dissipate vibrational energy as heat through the stretching and relaxation of long polymeric molecule chains [Ref. 6]. The change of the modulus will affect

the damping capability of the material. Thus, the viscoelastic material properties, such as shear modulus and modal loss factor, will vary depending on the temperature and frequency.

The properties of 3M ISD-112 viscoelastic material usually display as a "reduced frequency nomogram." The reduced frequency nomogram display the viscoelastic material's loss factor and shear modulus varying with temperature and frequency. The reduced frequency nomogram for 3M ISD-112 is shown in Figure 2.1. To find the loss factor and shear modulus using the nomogram first we should know the temperature and the corresponding frequency then go into the nomogram with temperature diagonally down the page and frequency horizontally to the left until the two lines intersect. Then from the intersect point going up or down to intersect the loss factor or shear modulus curve . Reading the intersect point we can get the loss factor or shear modulus horizontally from the scale from the left [Ref. 8].

C. CONSTRAIN VISCOELASTIC DAMPING

Constrained viscoelastic layer damping treatment is one of the most efficient ways of introducing damping into a structure. Pocket plate And floating element are two new configurations of this treatment. The component of those plates are standard 6061-T6 aluminum alloy plate and 3M ISD-112 viscoelastic material as damping material.

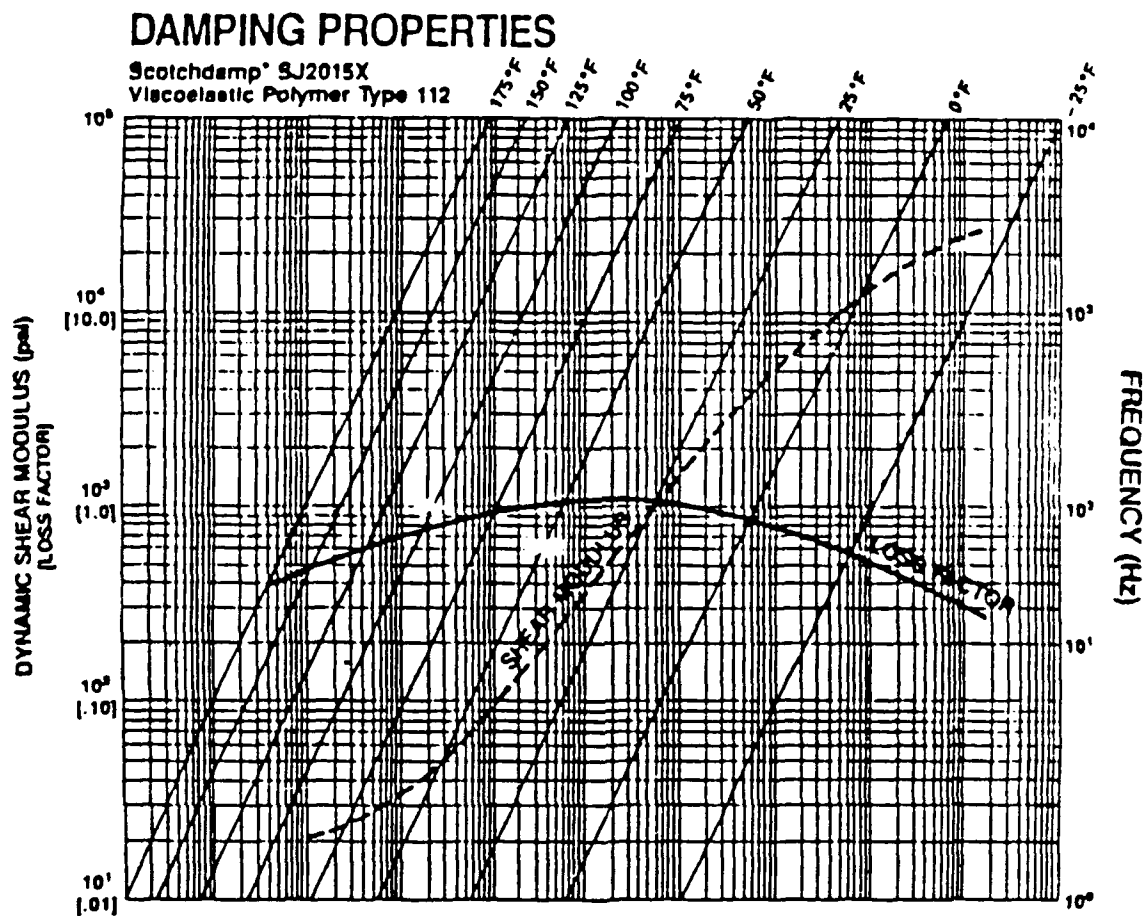


Figure 2.1. Reduced Frequency Normogram for 3M ISD-112 [Ref. 6].

III. EXPERIMENT

A. TESTING ARRANGEMENT

Experimental testing was performed on each of the two damping configurations and an undamped reference plate. In order to approximate the free-free boundary condition, each plate was suspended from the roof of the testing chamber using elastic cords as shown in Figure 3.1. All the tests were performed in a temperature controlled environmental chamber which enabled temperatures to be maintained within ± 0.5 °C. The primary component and user interface was the Hewlett-Packard (HP) 3562A Dynamic Signal Analyzer (DSA). The HP-3562A was used to provide a swept sine signal to a vibration generator, and to analyze the returning data signals from the shaker and accelerometer. In addition, the HP-3562A computed the frequency response and coherence over a range of 40 Hz to 1040 Hz using the discrete Fourier Transform in the swept sine mode. Ten data were taken and averaged at each data point using a frequency resolution of 2.5 Hz per point. The source level output to the vibration generator was set at 1.5 volts.

The testing set up is shown in Figure 3.2. Swept sine linear sweep source signal were fed from the output jack of the HP-3562A to a Wilcoxon F3 vibration generator via the piezoelectric output of a Wilcoxon PA7C power amplifier. The vibration generator was mounted 73.48 cm (28.93 in) from one end, and 12.7 cm (5.0 in) from the front edge of each specimen as shown in

Figure 3.3. An integral force transducer was mounted in the base of the vibration generator to measure the force input to the plate. This force signal was then fed to input channel one of the DSA via a PCB 462-A charge amplifier. Plate accelerations were recorded at various points using a PCB 303A-03 accelerometer as shown in Figure 3.3. Acceleration data were fed to input channel two of the DSA via a PCB 480D06 power unit and a PCB 482A05 power supply. Frequency response and coherence data was then recorded on disk for further analysis.

Temperatures inside the testing chamber were maintained using a NESLAB RTE-8 refrigerated circulating bath which pumped fluid through a small heat exchanger in the testing chamber as shown in Figure 3.2. In order to accurately monitor the temperature of the plates, a small thermocouple was inserted in the base of each plate.

B. TESTING PROCEDURE

1. Undamped Preference Plate

An undamped, reference, frequency response measurement was made at a temperature of 15.6 °C (60 °F) to set a standard response as a reference to compare the effectiveness with the damping treated plates. The undamped frequency response was recorded over a frequency range of 40-1040 Hz using a resolution of 2.5 Hz per point in the DSA. It does not depend on temperature.

2. Damped Plate Measurements

Frequency response measurements of the damped plates were made at three temperatures of 4.44 °C (40 °F), 15.6 °C (60 °F), and 26.7 °C (80 °F) at several nodes on the plates in order to get the damped response of as many modes as possible. The frequency response plots shown in this reports were taken at the location "1" indicated in Figure 3.3, unless otherwise noted. The locations of these nodes are shown in Figure 3.3. Responses were recorded over a frequency range of 40-1040 Hz with a resolution of 2.5 Hz per point in the DSA. Zoom measurements were also made to capture better data for certain modes. Modal loss factors were then estimated from the frequency response and coherence measurements using a curve-fitting technique described in reference [Ref. 10]. The curve fitting data were obtained from the DSA. The modal loss factors were averaged from the six measured nodes.

C. POCKET PLATE RESULTS

The cover for the milled pocket plate was secured in two ways: spot welded and continuous line welded. For the spot welded pocket plate, the weld configuration is shown in Figure 3.4. The continuous line weld was performed using a MILLERMATIC 200 welding machine. The machine has a constant potential DC arc welding power source and wire control/feeder system. It was carefully welded not to significantly raise the temperature

around the welded area and not to damage the viscoelastic layer. They were tested at 4.44 °C (40 °F), 15.6 °C (60 °F), and 26.7 °C (80 °F) so that the effects of temperature on the damping treatment could be determined. From the test we will examine the effects of the heat on the viscoelastic material from welding.

1. Spot Welded Pocket Plate Results

Three plots of frequency responses of spot welded pocket plate at three different temperatures are shown in Figures 3.5 through 3.7. Comparison with the responses of the reference plate shows good damping and the viscoelastic layer was not damaged by welding. Due to the closely coupling of modes, loss factors for all modes were not measured. The frequency response of the damped plate is characterized by a frequency shift to the left and a reducing and smoothing of the frequency response compare to the undamped reference plate. The spot welded pocket plate was also effective at reducing the amplitude of the response peaks over the entire spectrum of treatment. The response curve became more rounded and the effects of the damping layer are seen as frequency increases. The modal loss factors for the spot welded pocket plate of three different temperature are listed in Table 3.1 and are plotted in Figure 3.8. The effect of temperature on the damping was obvious as shown in Figure 3.9. The results show the trend of increased damping with temperature decrease, and a corresponding shift of modal frequencies to the right as the viscoelastic material become stiffer in this temperature range. At lower testing temperature the viscoelastic layer

become stiffer and damping levels were increased. The modal coupling will increase the modal loss factor values at frequency above 780 Hz. Hence, the measured modal loss factors in this range are not reliable.

**TABLE 3.1. MEASURED MODAL LOSS FACTORS FOR THE SPOT
WELDED POCKET PLATE AT 4.44/15.6/26.7 °C.**

4.44 °C (40 °F)		15.6 °C (60 °F)		26.7 °C (80 °F)	
<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>
64.6	0.094	62.1	0.067	60.0	0.044
95.9	0.076	93.4	0.042	91.1	0.025
146.9	0.092	142.0	0.056	138.2	0.031
200.9	0.088	194.9	0.060	187.9	0.035
319.0	0.079	308.9	0.051	299.4	0.040
446.1	0.059	437.5	0.041	424.8	0.032
576.8	0.067	495.6	0.036	445.1	0.043
642.4	0.072	565.3	0.043	547.7	0.034
711.5	0.076	625.7	0.047	613.0	0.048
857.0	0.054	643.2	0.049	633.5	0.042
		687.0	0.044	677.1	0.057
		841.9	0.056	829.2	0.038
		891.5	0.077		
		923.0	0.090		

2. Line Welded Pocket Plate Results

The effects of temperature on the continuous welded pocket plate were also investigated. Three plots of frequency response compared with the undamped reference plate at three different temperature are shown in Figures 3.10 through 3.12. From the figure it shows good damping, indicating the viscoelastic layer was not damaged by the heat of welding. The measured modal loss factor for the line welded pocket plate of three different temperatures are listed in Table 3.2 and are shown in Figure 3.13. The trend of increasing damping with decreasing temperature and shift of corresponding modal frequency to the left were similar to the spot welded pocket plate. The effect of temperature on the damping of line weld pocket plate was shown in Figure 3.14. Comparison of spot and line welded pocket plate at 4.44 °C (40 °F), 15.6 °C (60 °F), and 26.7 °C (80 °F) are shown in Figures 3.15 through 3.17. As can be seen in these figures, we the spot welded pocket plate has more damping effect than line welded one and the corresponding modal frequency shift to the left. The reason is line welded pocket plate is more constrained than the spot welded. Therefore, the cover plate of line welded pocket plate cannot induce shear deformation in the viscoelastic layer as well as spot welded pocket plate, and produce less damping than the spot welded pocket plate.

**TABLE 3.2. MEASURED MODAL LOSS FACTORS FOR THE LINE
WELDED POCKET PLATE AT 4.44/15.6/26.7 °C**

4.44 °C (60 °F)		15.6 °C (60 °F)		26.7 °C (80 °F)	
<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>
71.4	0.038	70.1	0.030	69.7	0.018
125.8	0.042	122.4	0.058	120.8	0.028
170.0	0.020	168.3	0.013	167.5	0.011
245.8	0.047	238.4	0.034	235.4	0.019
305.1	0.027	368.6	0.031	363.1	0.020
377.5	0.037	469.1	0.042	463.0	0.054
526.4	0.042	634.5	0.025	627.1	0.019
640.2	0.031	670.8	0.042	667.7	0.056
680.3	0.041	713.9	0.030	708.7	0.041
720.8	0.039	775.2	0.036	765.2	0.045
790.1	0.034	915.4	0.033	906.4	0.039
923.0	0.030				

D. FLOATING ELEMENT PLATE RESULTS

The milled floating element plate configuration was welded in two cases as for the pocket plate. The floating element was made slightly smaller than the surrounding structure thus allowing the floating element to act as a "true" constrain layer. That makes the viscoelastic layer have more space to shear. It thus have more shear deformation than the pocket plate and the modal loss factor will theoretically be higher than the pocket plate cases.

1. Spot Welded Floating Element Plate Results

Three plots of frequency response for the spot welded floating element plate are shown in Figures 3.18 through 3.20. Comparison with the reference undamped plate shows good damping. The spot weld floating element plate is very effective as the response shows a good reduction in peak modal response. Measured modal loss factors for three temperatures are listed in Table 3.3 and are shown in Figure 3.21. From the figures we found that the frequency response of the floating element configuration is characterized by a frequency shift to the left and a smoothing of the response as frequency increases. This trend is similar to the previous pocket plate cases. The effect of temperature on damping is quite clearly as shown in Figure 3.22.

**TABLE 3.3. MEASURED MODAL LOSS FACTORS FOR THE SPOT
WELDED FLOATING ELEMENT PLATE AT
4.44/15.6/26.7 °C.**

4.44 °C (60 °F)		15.6 °C (60 °F)		26.7 °C (80 °F)	
<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>
66.6	0.075	66.0	0.089	62.6	0.053
108.7	0.057	104.9	0.040	103.3	0.038
163.1	0.112	154.0	0.094	148.6	0.056
216.9	0.092	211.4	0.058	205.0	0.059
299.5	0.170	272.8	0.063	268.4	0.036
334.0	0.091	323.5	0.075	316.0	0.060
443.7	0.113	435.8	0.090	424.8	0.067
453.7	0.070	508.1	0.089	481.6	0.070
524.4	0.090	540.6	0.115	558.7	0.084
579.9	0.120	618.7	0.121	608.2	0.098
628.9	0.167	656.7	0.100	633.3	0.103
664.3	0.130	708.6	0.088	685.0	0.132
711.7	0.120	857.6	0.089	828.1	0.126
865.9	0.100	935.4	0.064	854.2	0.083
896.7	0.100			893.4	0.102

2. Line Welded Floating Element Plate Results

Plots of frequency responses for the line welded floating element plate at three different temperatures are shown in Figure 3.23 through 3.25. Comparison with the undamped reference plate shows good damping effect. The frequency response of the damped plate is the same with the previous cases. The measured modal loss factors for the line welded floating element plate of three different temperatures are listed in Table 3.4 and are plotted in Figure 3.26. The temperature effects are clearly evident as shown in Figure 3.27. Comparisons of frequency responses of the spot and line welded floating element plate at three temperatures are shown in Figures 3.28 through 3.30. Again, the figures show that spot welded floating element has better damping effect because it allows more shear deformation than the line welded one. The peaks are smooth along the whole range. Comparisons of spot welded pocket plate and floating element plate are shown in Figures 3.31 through 3.33. The other comparisons of line welded pocket plate and floating element plate are shown in Figures 3.34 through Figure 3.36. From these comparisons it is clear that the floating element plate has better damping than the pocket plate. The curves of frequency response are more smooth and the rounded peaks are shifted to the left. Reasons for this are the added constraining effect of the floating element and additional layer of damping material present.

**TABLE 3.4. MEASURED MODAL LOSS FACTORS FOR THE LINE
WELDED FLOATING ELEMENT PLATE AT
4.44/15.6/26.7 °C.**

4.44 °C (60 °F)		15.6 °C (60 °F)		26.7 °C (80 °F)	
<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>
73.1	0.043	71.3	0.039	70.3	0.029
126.8	0.063	124.7	0.040	124.7	0.022
175.7	0.055	171.7	0.035	169.8	0.024
254.0	0.045	248.6	0.033	246.3	0.021
381.8	0.080	368.8	0.168	394.0	0.109
486.7	0.080	476.1	0.062	471.6	0.061
525.7	0.063	516.4	0.101	512.4	0.086
537.8	0.130	653.5	0.096	647.2	0.093
674.1	0.104	731.1	0.081	717.3	0.078
748.0	0.083				
848.0	0.133				

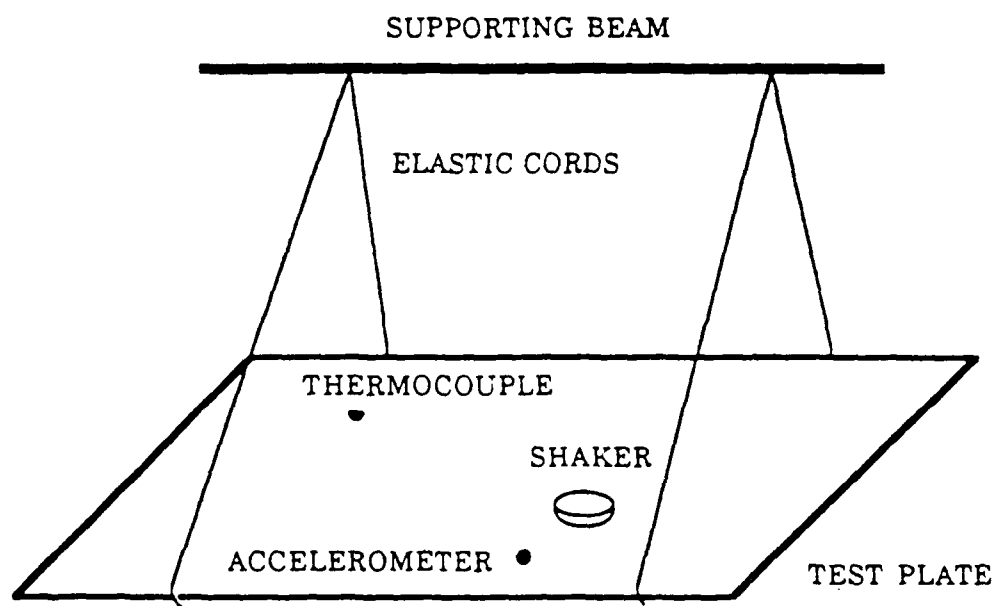


Figure 3.1. Testing Configuration In Testing Chamber.

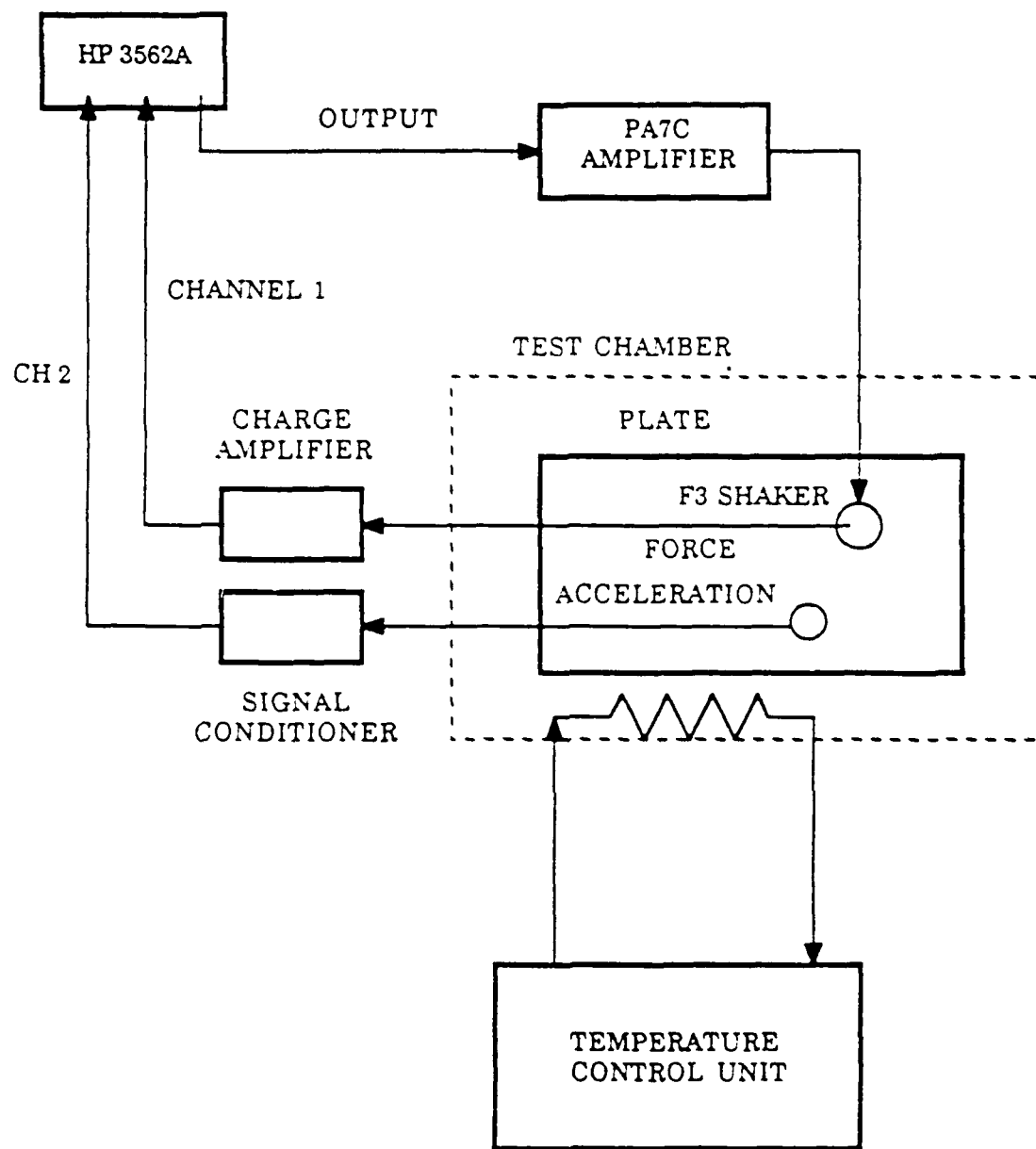


Figure 3.2. Schematic Diagram of Testing System.

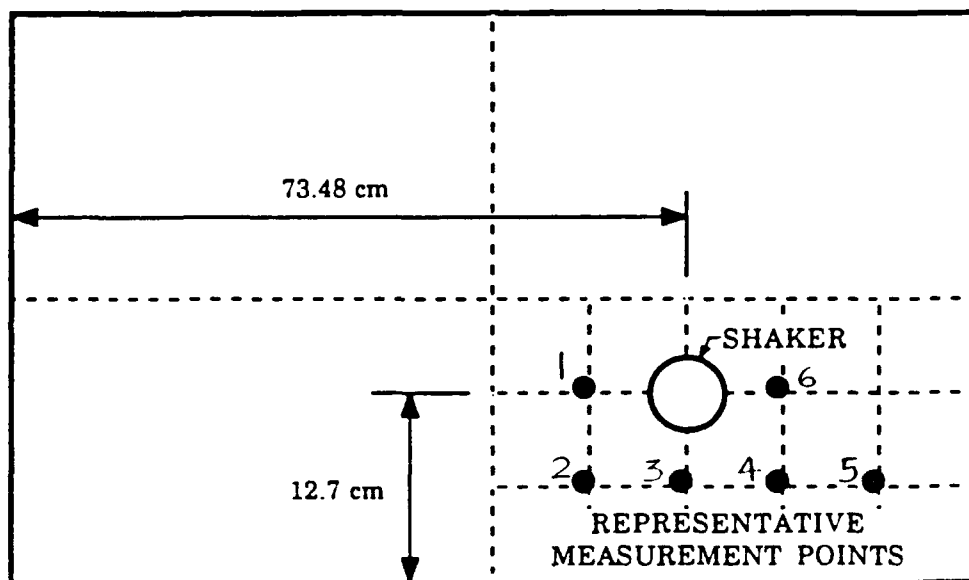


Figure 3.3. Shaker and Accelerometer Location.

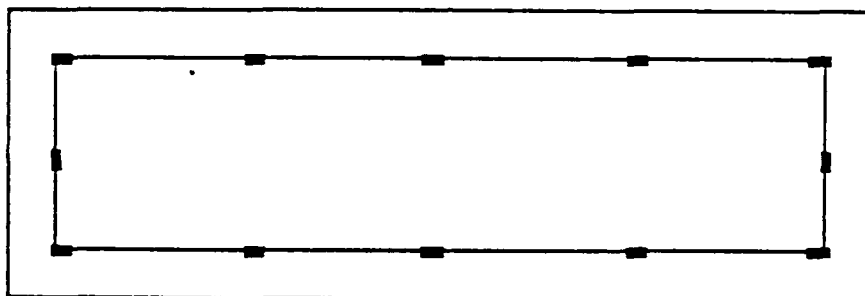


Figure 3.4. Location of Spot Welds on the Cover plate of Pocket Plat Configuration.

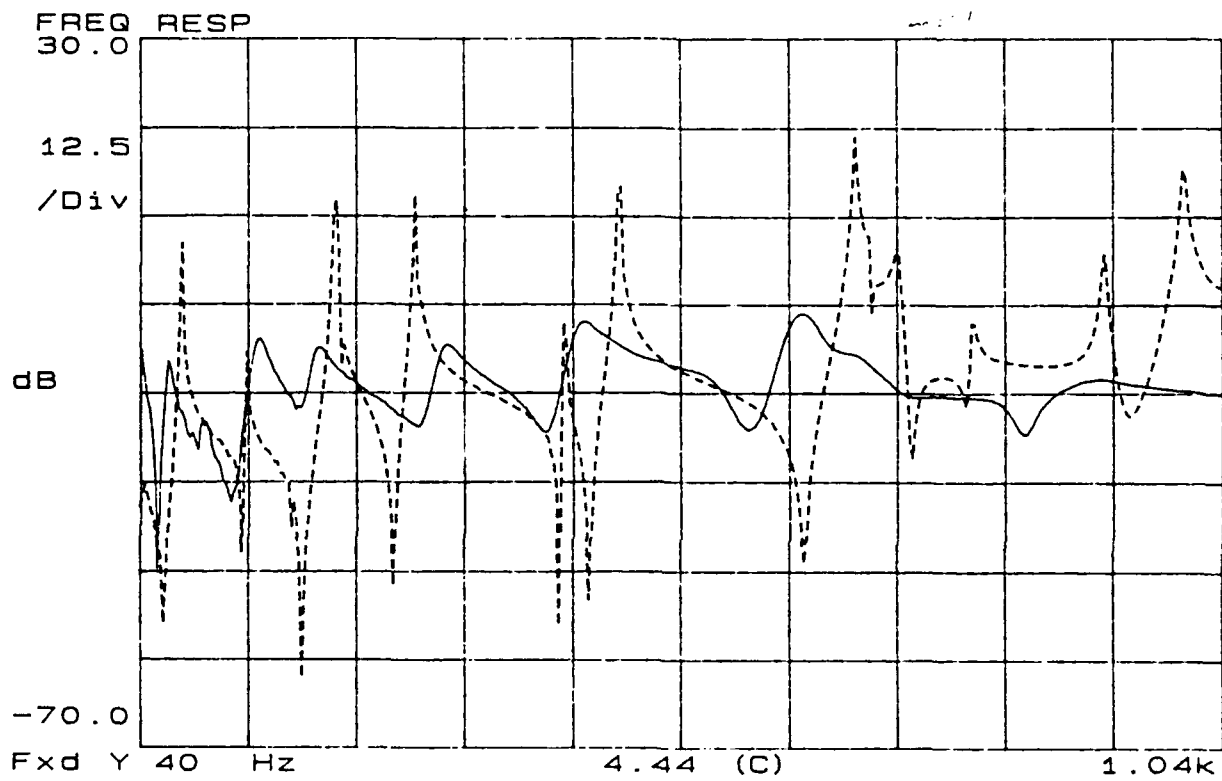


Figure 3.5. Measured Frequency Response of the Spot Welded Pocket Plate Configuration at 4.44 °C.

[- - - - : undamped response; - - - - : damped response]

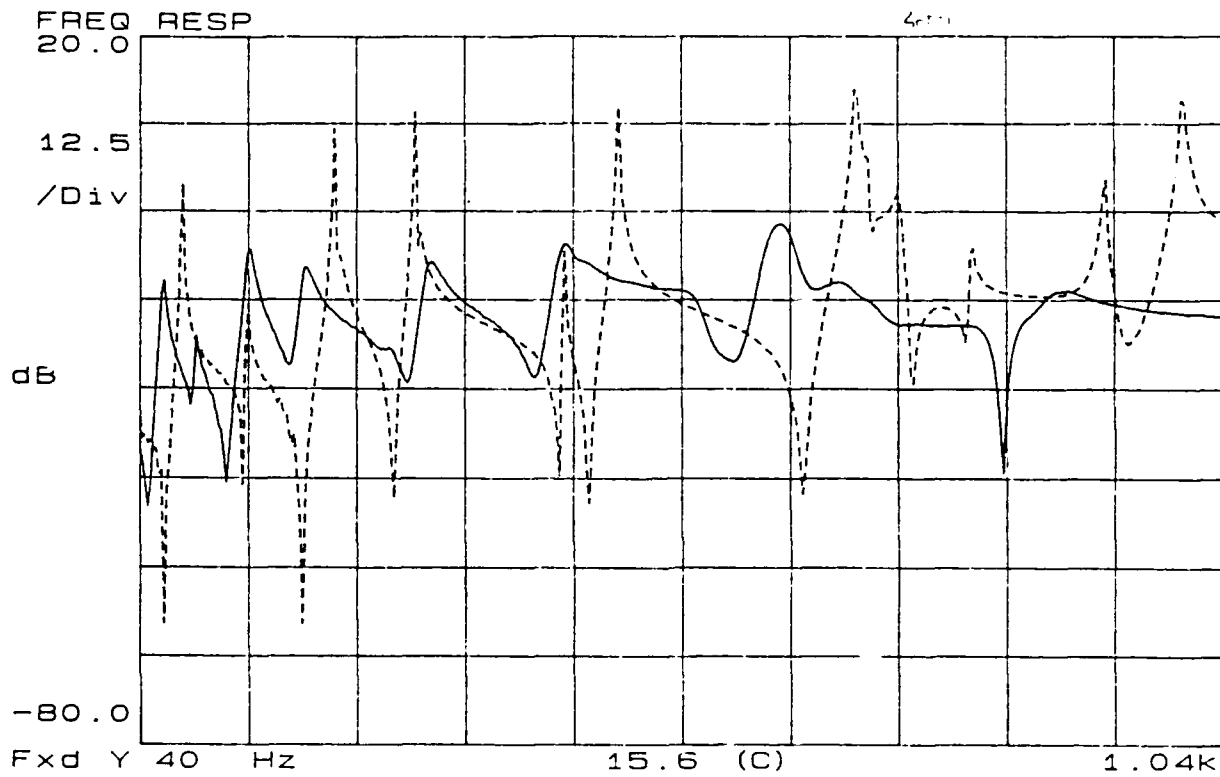


Figure 3.6. Measured Frequency Response of the Spot Welded Pocket Plate Configuration at 15.6 °C.

[- - - - : undamped response; - - - - : damped response]

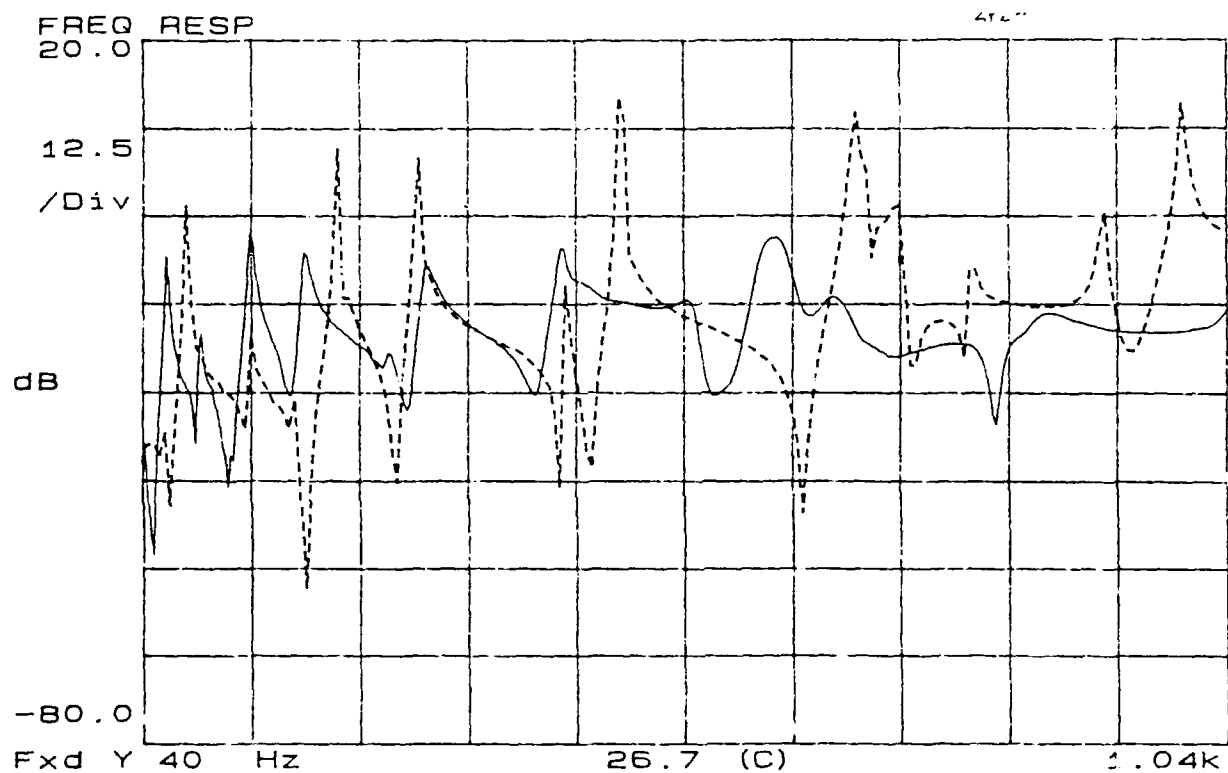


Figure 3.7. Measured Frequency Response of the Spot Welded Pocket Plate Configuration at 26.7 °C.

[- - - - : undamped response; ——— : damped response]

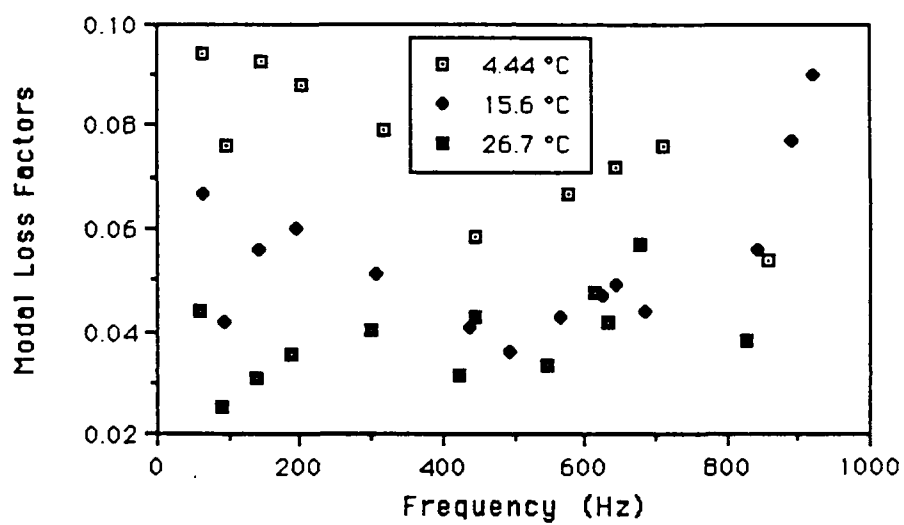


Figure 3.8. Measured Modal Loss Factor for the Spot Welded Pocket Plate at 4.44/15.6/26.7 °C.

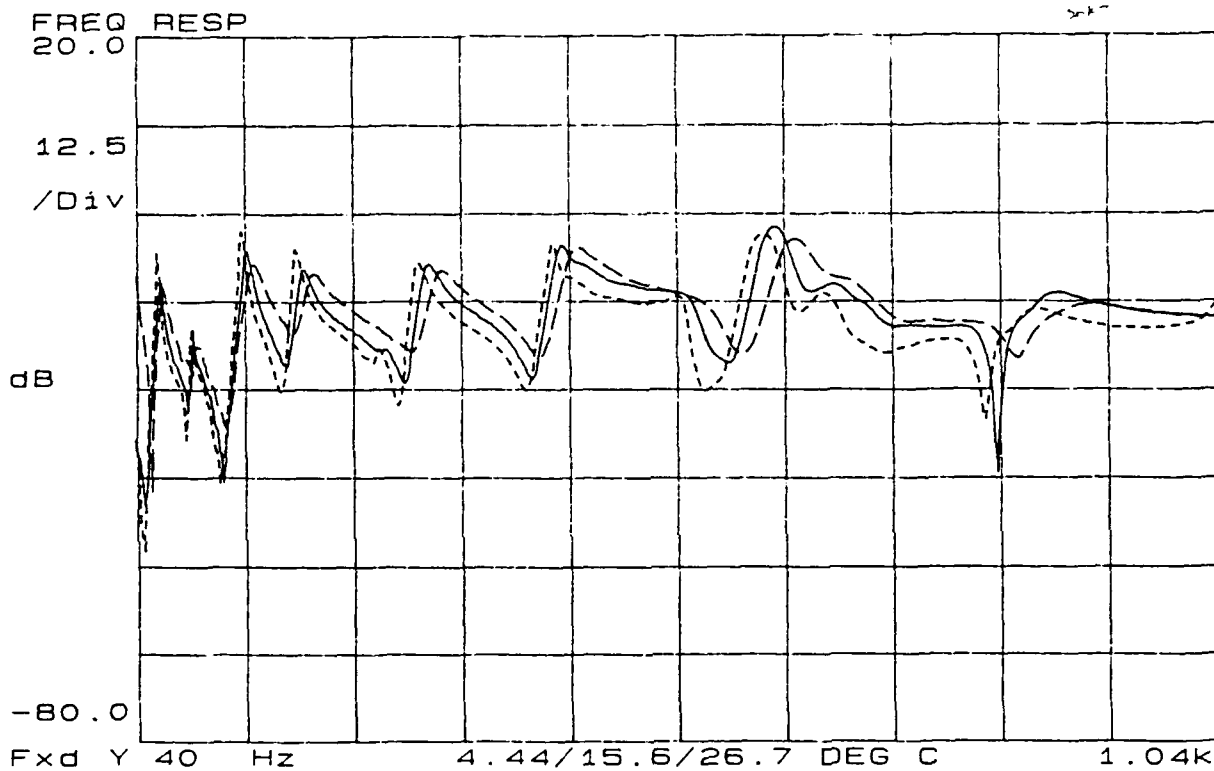


Figure 3.9. Measured Frequency Response of the Spot Welded Pocket Plate Configuration at 4.44/15.6/26.7 °C.

[— — — : 4.44 °C, — : 15.6 °C, - - - - : 26.7 °C]

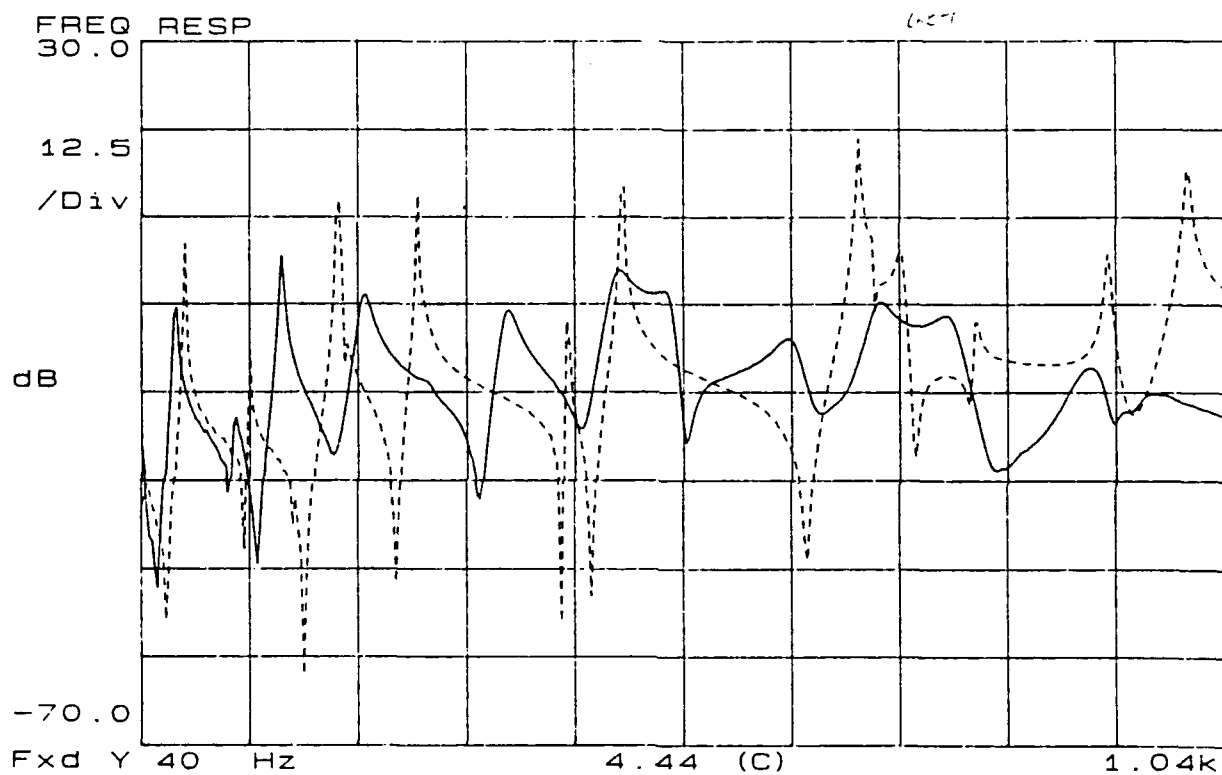


Figure 3.10. Measured Frequency Response of the Line Welded Pocket Plate Configuration at 4.44 °C

[- - - - : undamped response; ——— : damped response]

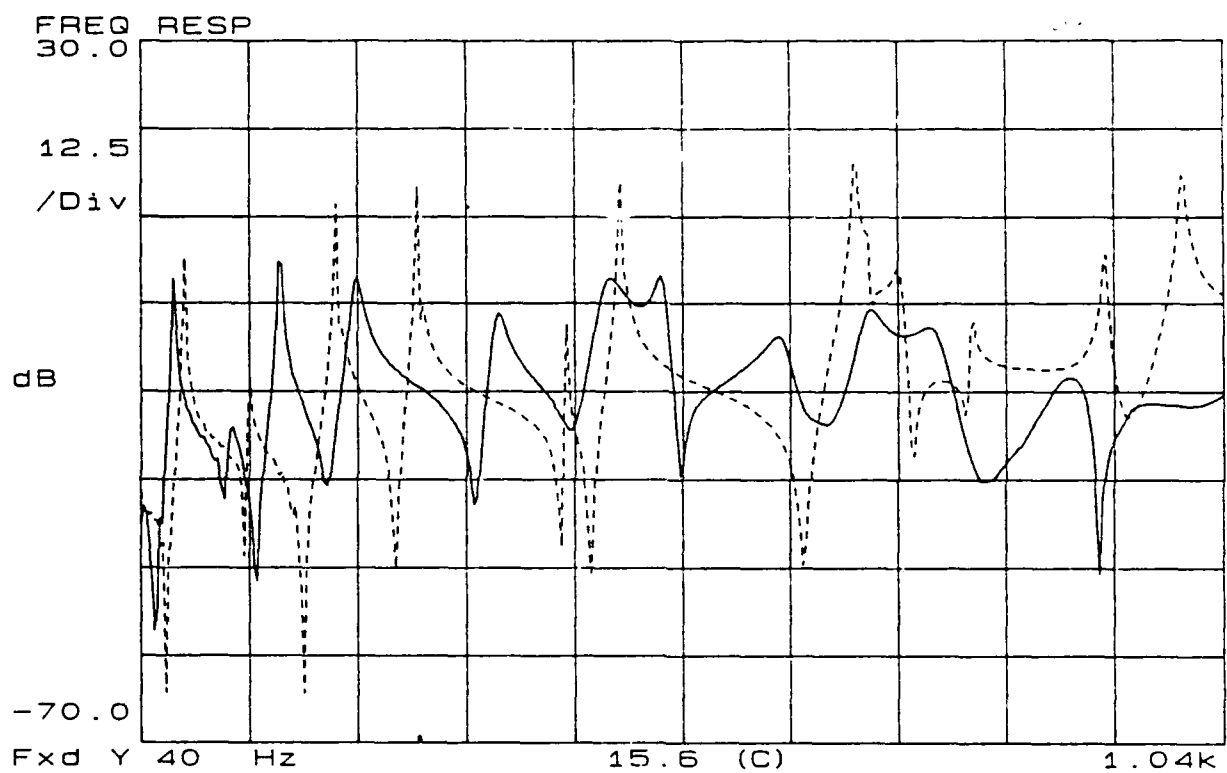


Figure 3.11. Measured Frequency Response of the Line Welded Pocket Plate Configuration at 15.6 °C.

[- - - - : undamped response; ----- : damped response]

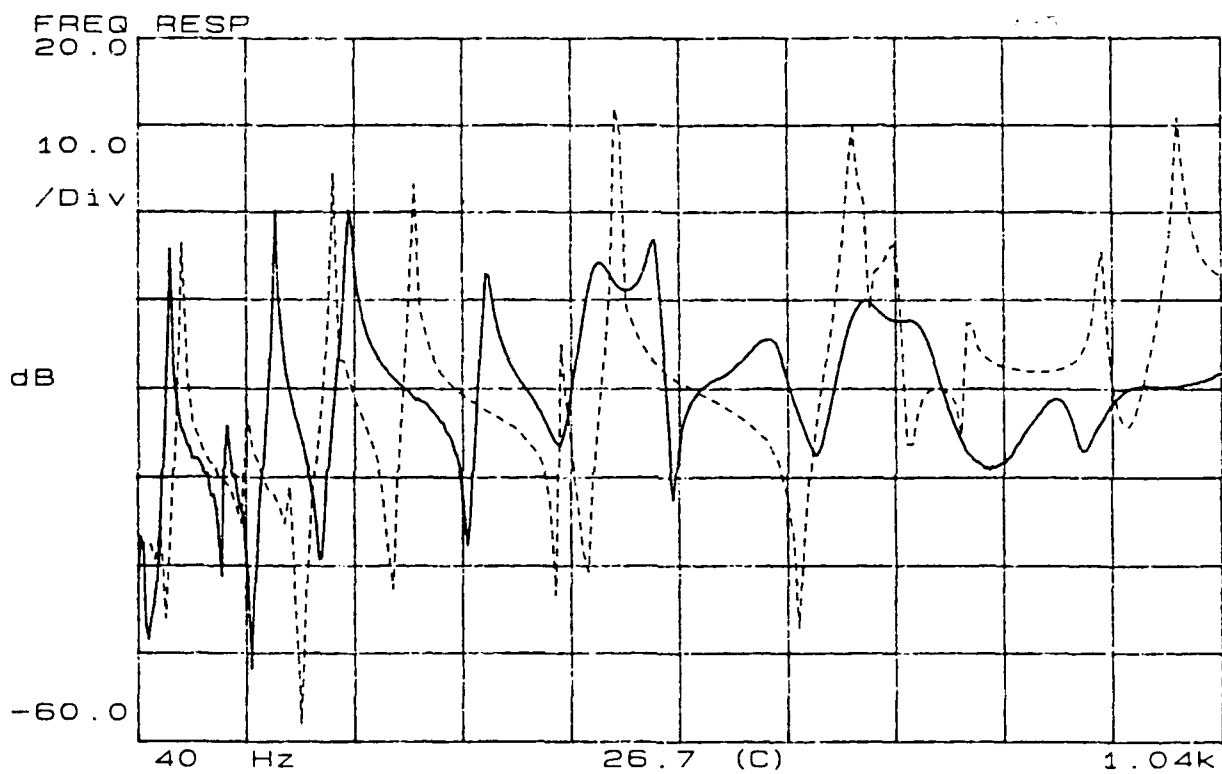


Figure 3.12. Measured Frequency Response of the Line Welded Pocket Plate Configuration at 26.7 °C.

[- - - - : undamped response; ——— : damped response]

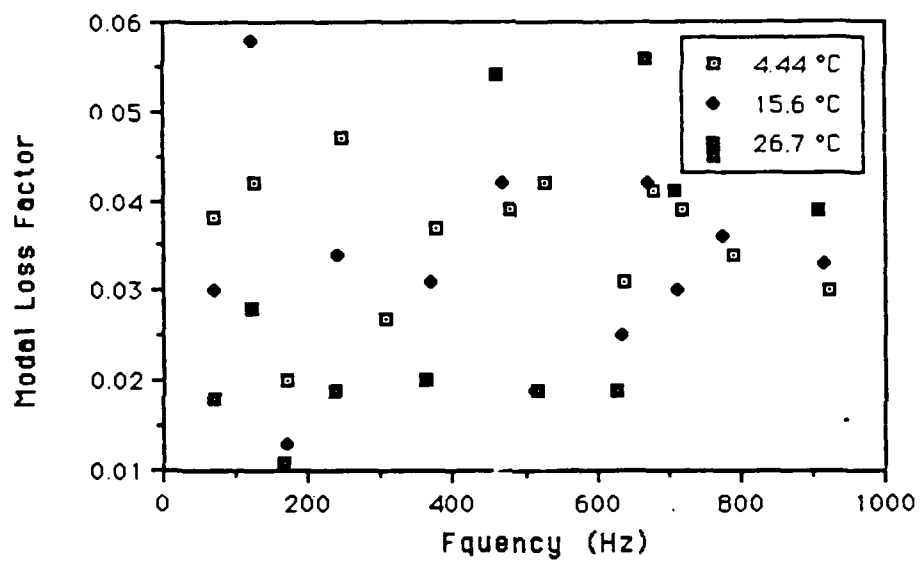


Figure 3.13. Measured Modal Loss Factors for the Line Welded Pocket Plate Configuration at 4.44/15.6/26.7 °C.

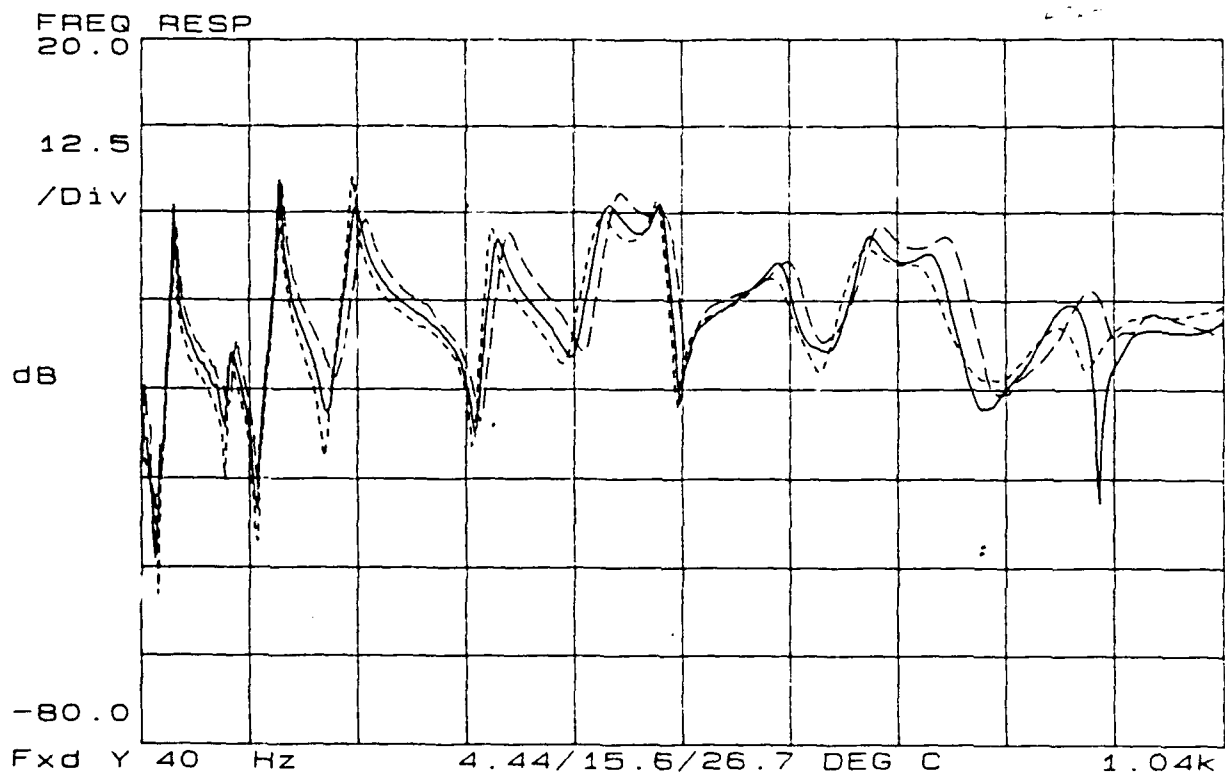


Figure 3.14. Measured Frequency Response of the Line Welded Pocket Plate Configuration at 4.44/15.6/26.7 °C.

[— — — : 4.44 °C, — : 15.6 °C, - - - : 26.7 °C]

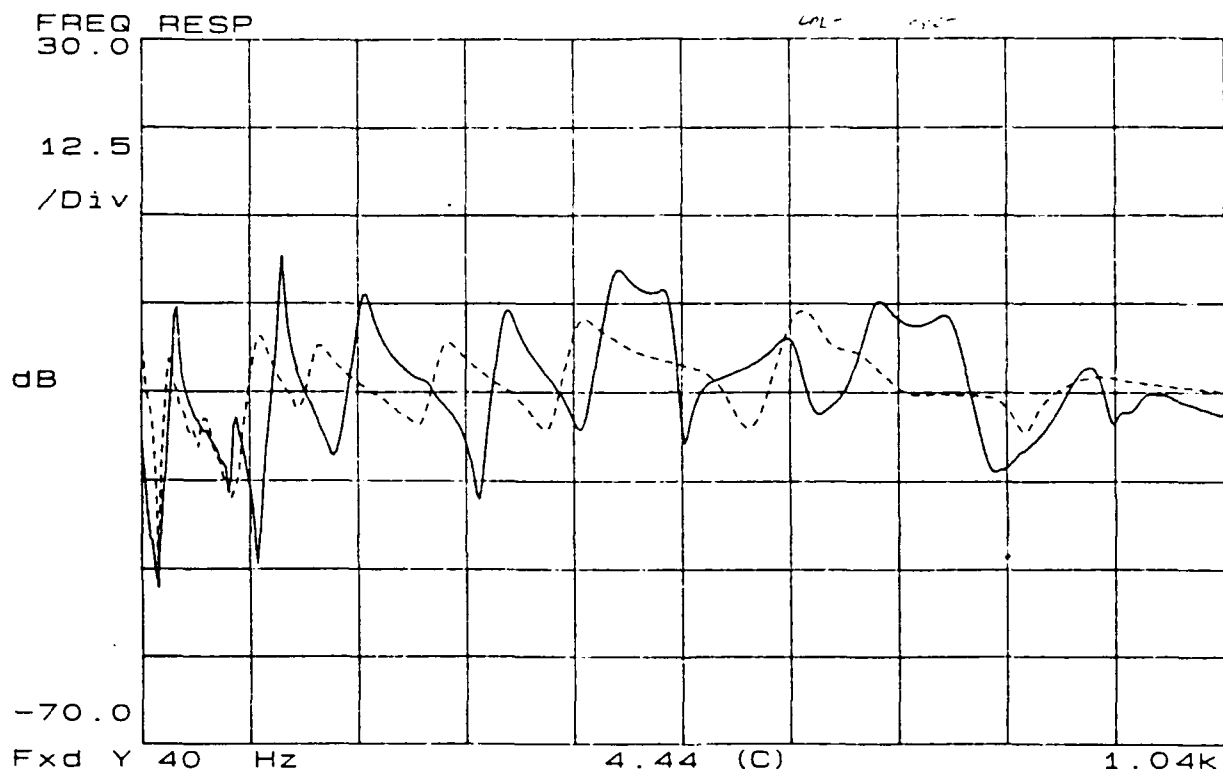


Figure 3.15. Comparison of Measured Frequency Responses of Spot and Line Welded Pocket Plates at 4.44 °C.

[- - - - : Spot Welded, — : Line Welded]

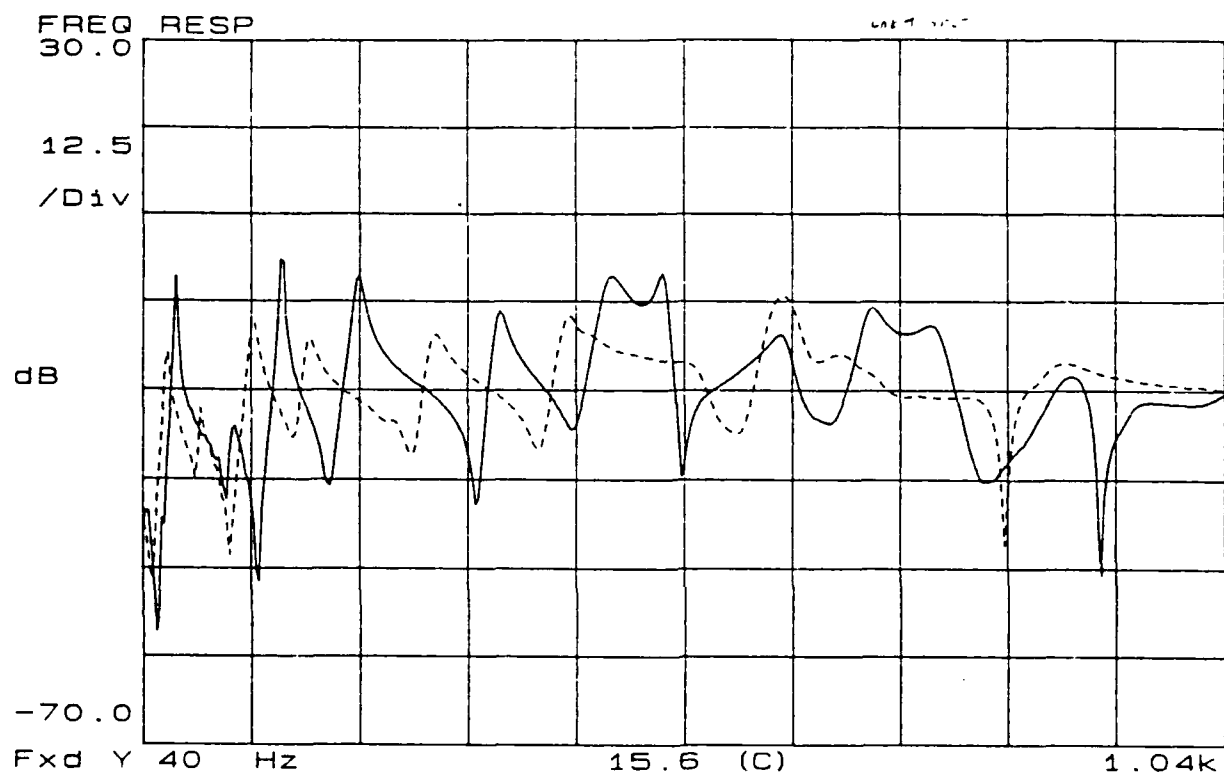


Figure 3.16. Comparison of Measured Frequency Responses of Spot and Line Welded Pocket Plates at 15.6 °C.

[- - - - : Spot Welded, — : Line Welded]

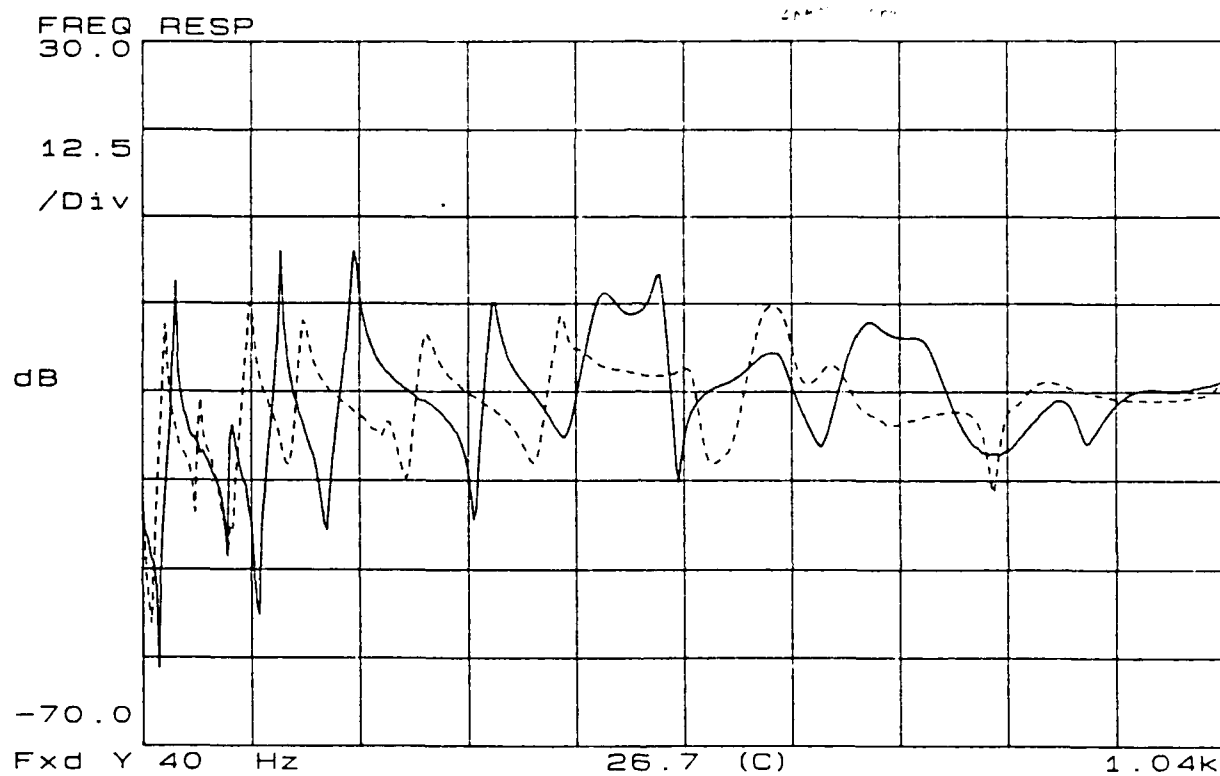


Figure 3.17. Comparison of Measured Frequency Responses of Spot and Line welded Pocket Plates at 26.7 °C.

[- - - - : Spot Welded, — : Line Welded]

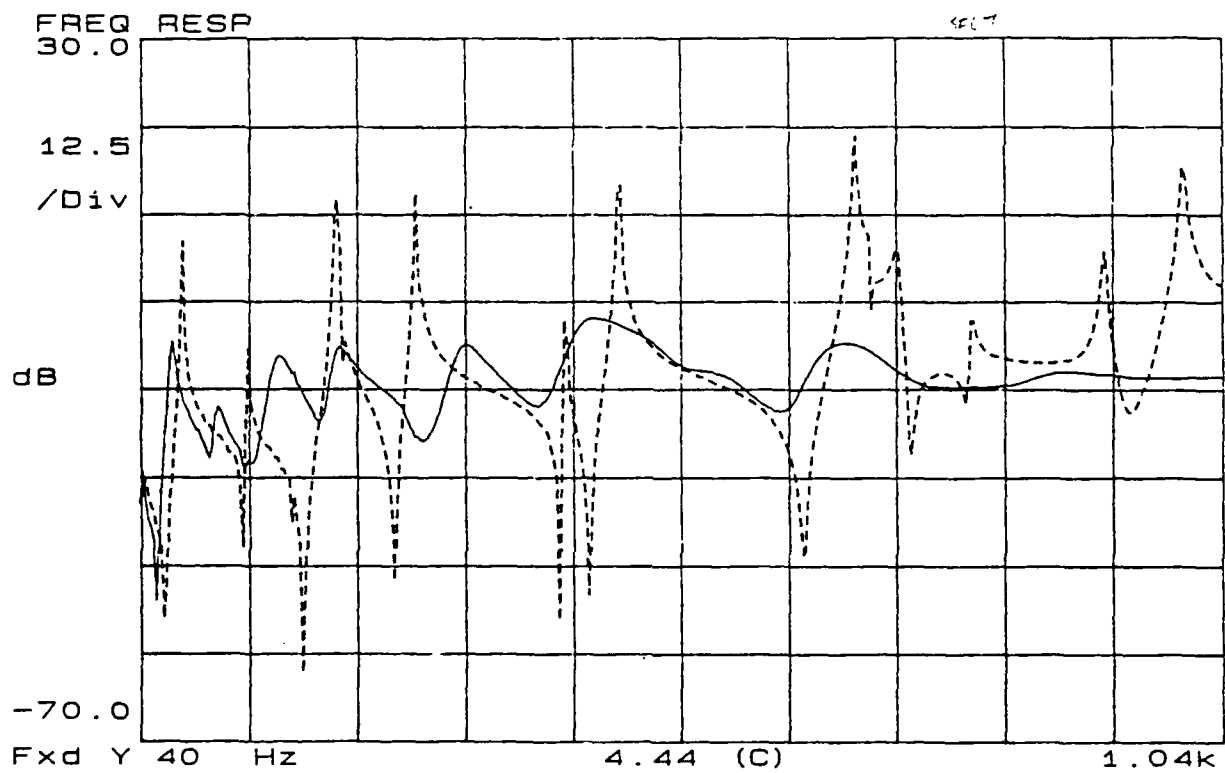


Figure 3.18. Measured Frequency Response of the Spot Welded Floating Element Plate at 4.44 °C.

[- - - - : undamped response; ——— : damped response]

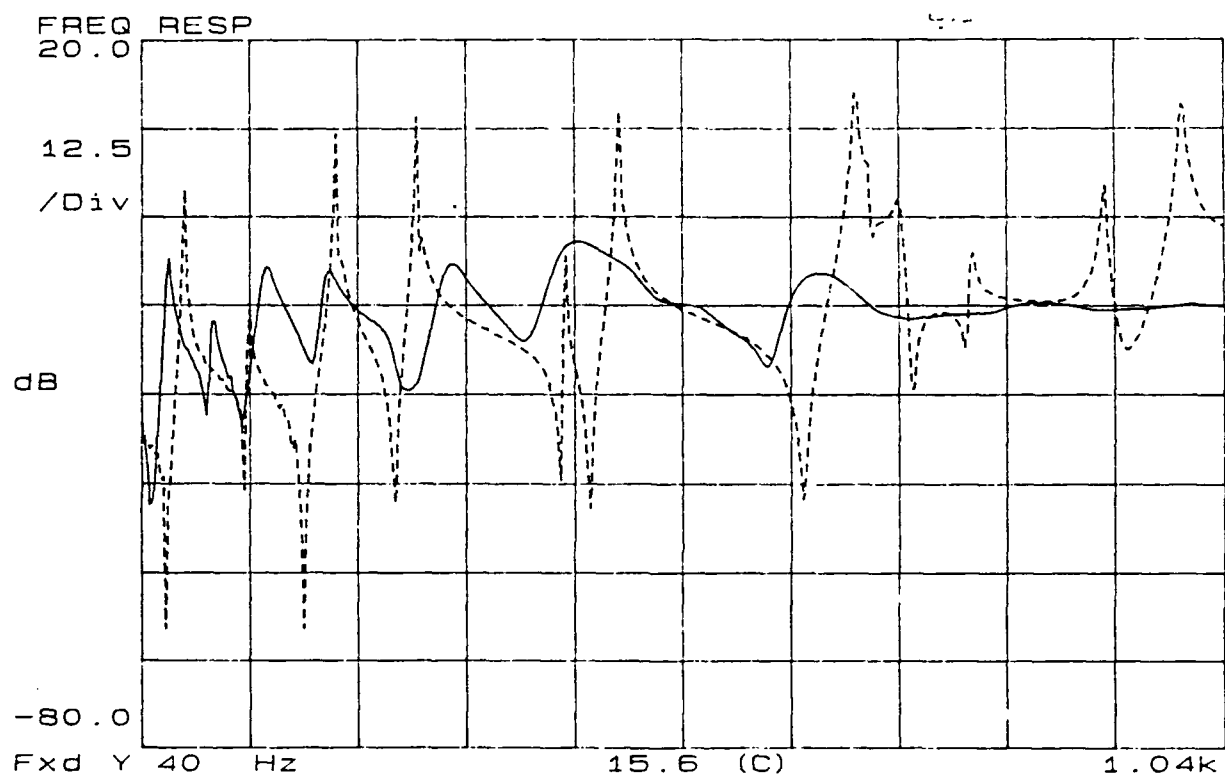


Figure 3.19. Measured Frequency Response of the Spot Welded Floating Element Plate at 15.6 °C.

[- - - - : undamped response; ——— : damped response]

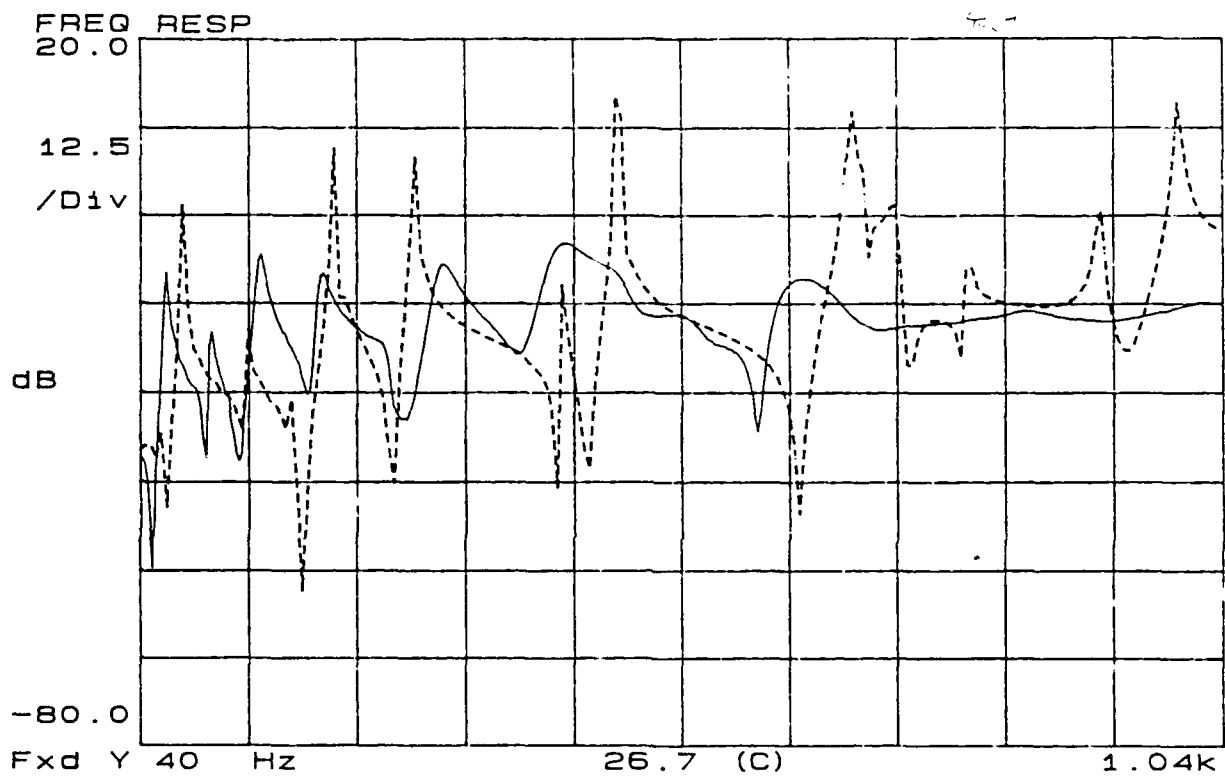


Figure 3.20. Measured Frequency Response of the Spot Welded Floating Element Plate at 26.7 °C.

[---- : undamped response; ——— : damped response]

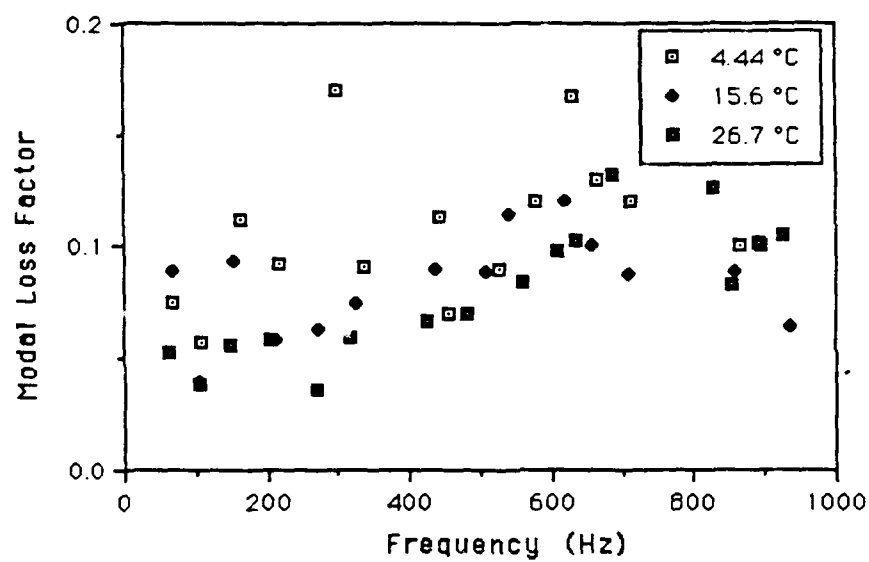


Figure 3.21. Measured Modal Loss Factors for the Spot Welded Floating Element Plate at 4.44/15.6/26.7 °C.

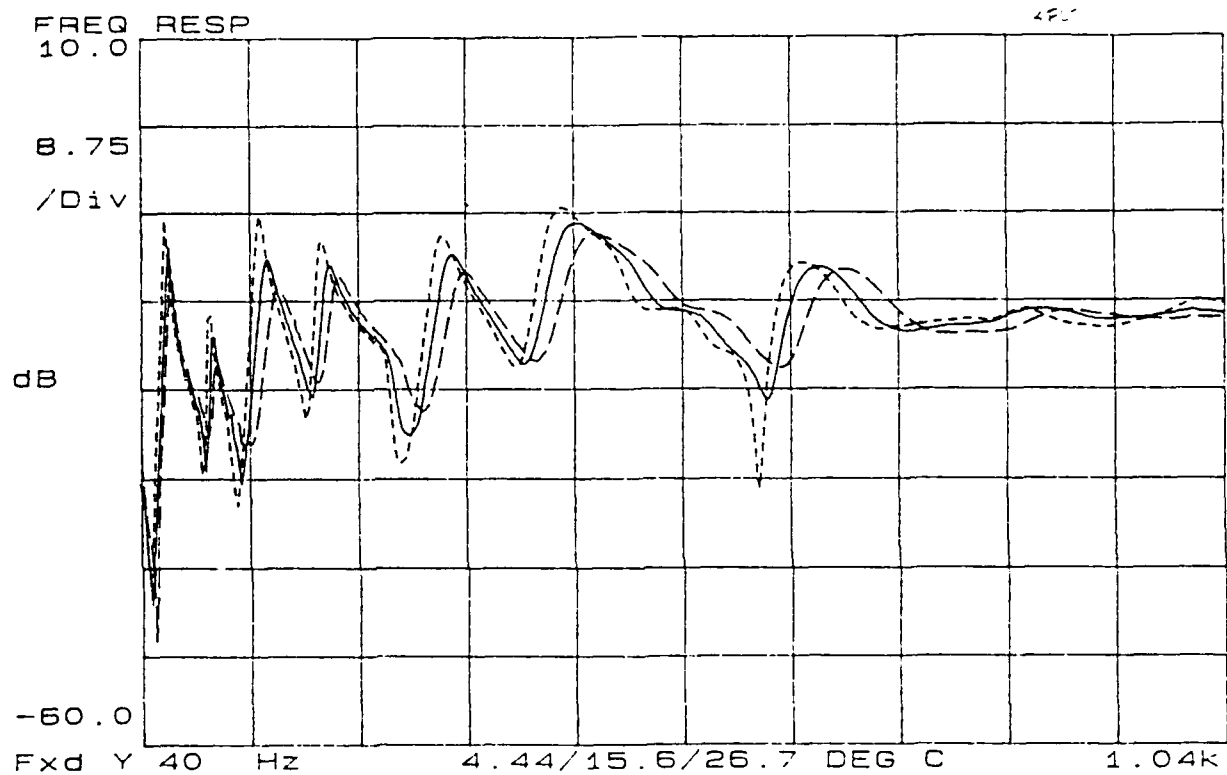


Figure 3.22. Measured Frequency Response of the Spot Welded Floating Element Plate at 4.44/15.6/26.7 °C.

[— — — : 4.44 °C, — : 15.6 °C, - - - - : 26.7 °C]

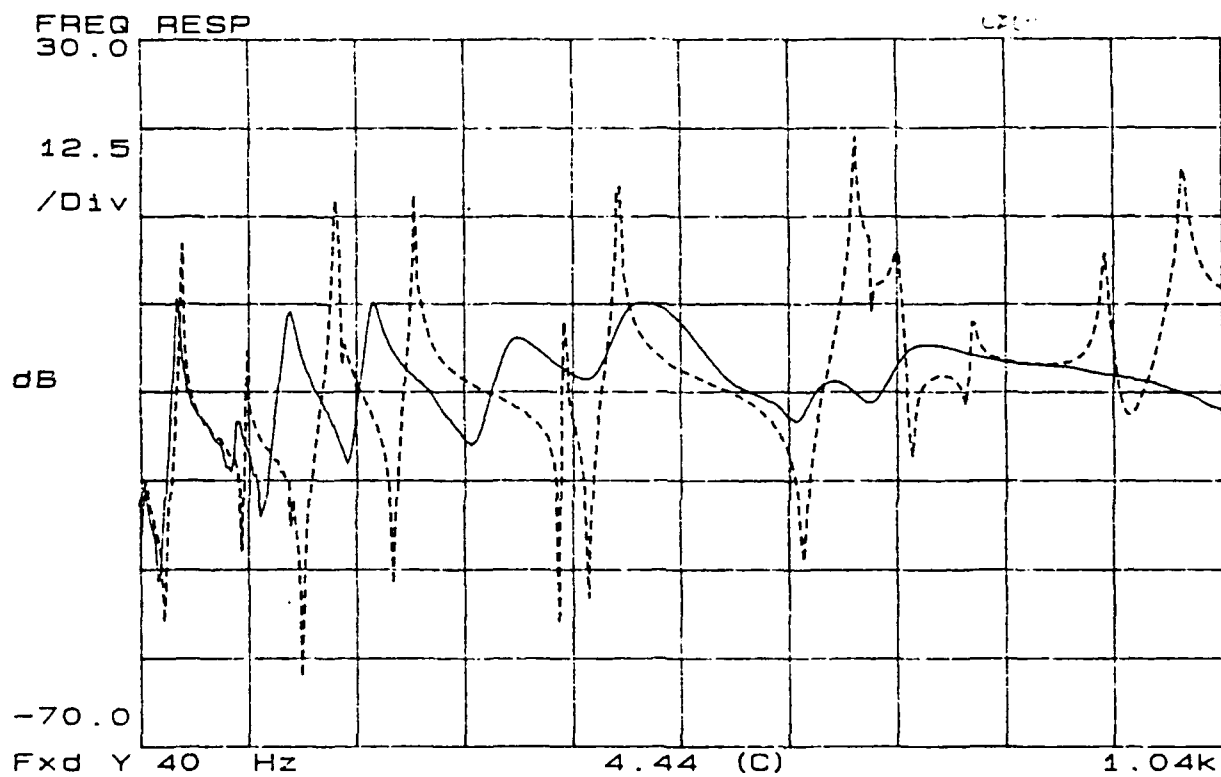


Figure 3.23 Measured Frequency Response of the Line Welded Floating Element Plate at 4.44 °C.

[- - - - : undamped response; ——— : damped response]

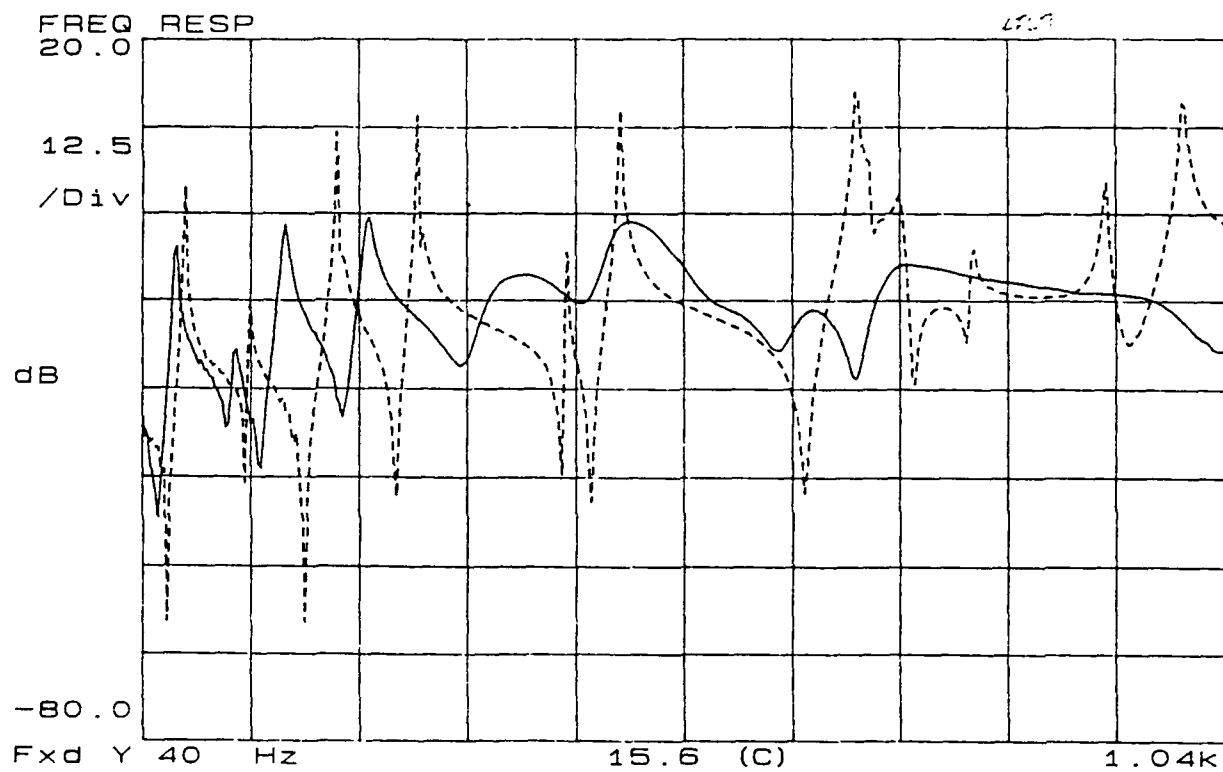


Figure 3.24. Measured Frequency Response of the Line Welded Floating Element Plate at 15.6 °C.

[- - - - : undamped response; - - - - : damped response]

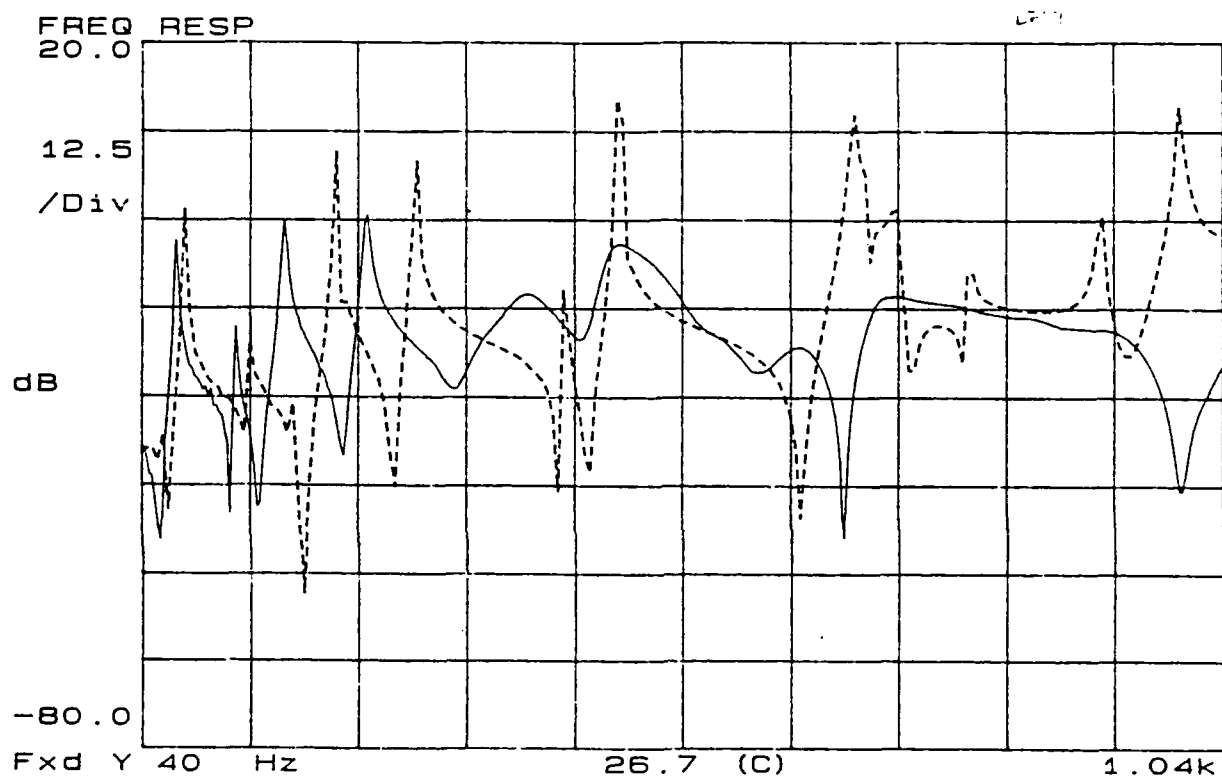


Figure 3.25. Measured Frequency Response of the Line Welded Floating Element Plate at 26.7 °C.

[- - - - : undamped response; - - - - : damped response]

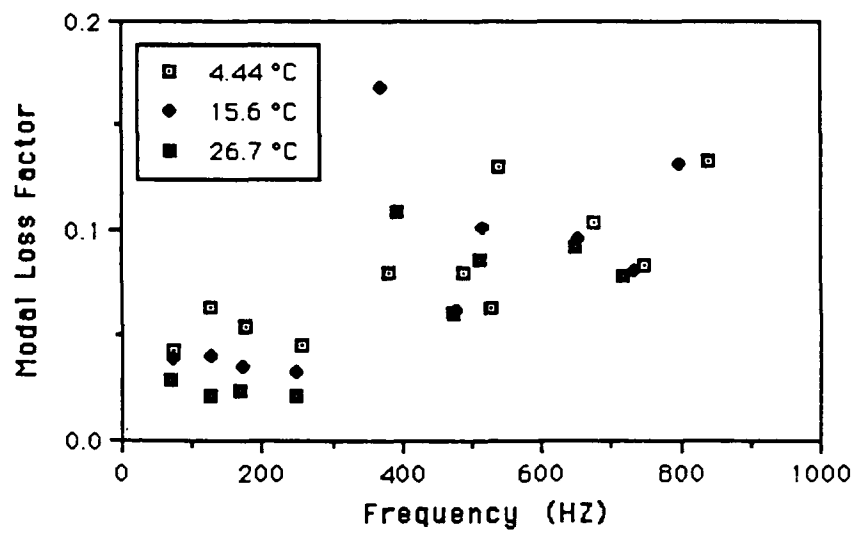


Figure 3.26. Measured Modal Loss Factors for the Line Welded Floating Element Plate at 4.44/15.6/26.7 °C.

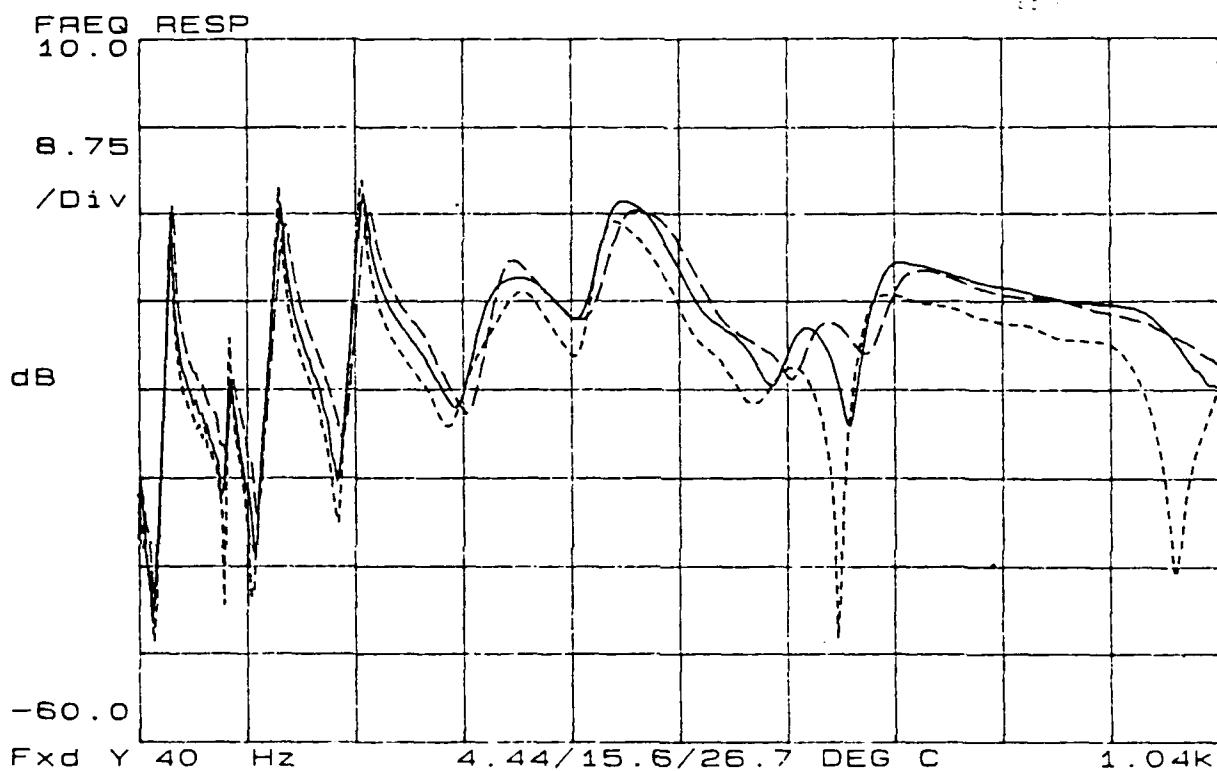


Figure 3.27. Measured Frequency Response of the Line Welded Floating Element Plate at 4.44/15.6/26.7 °C.

[— — — : 4.44 °C, — : 15.6 °C, - - - - : 26.7 °C]

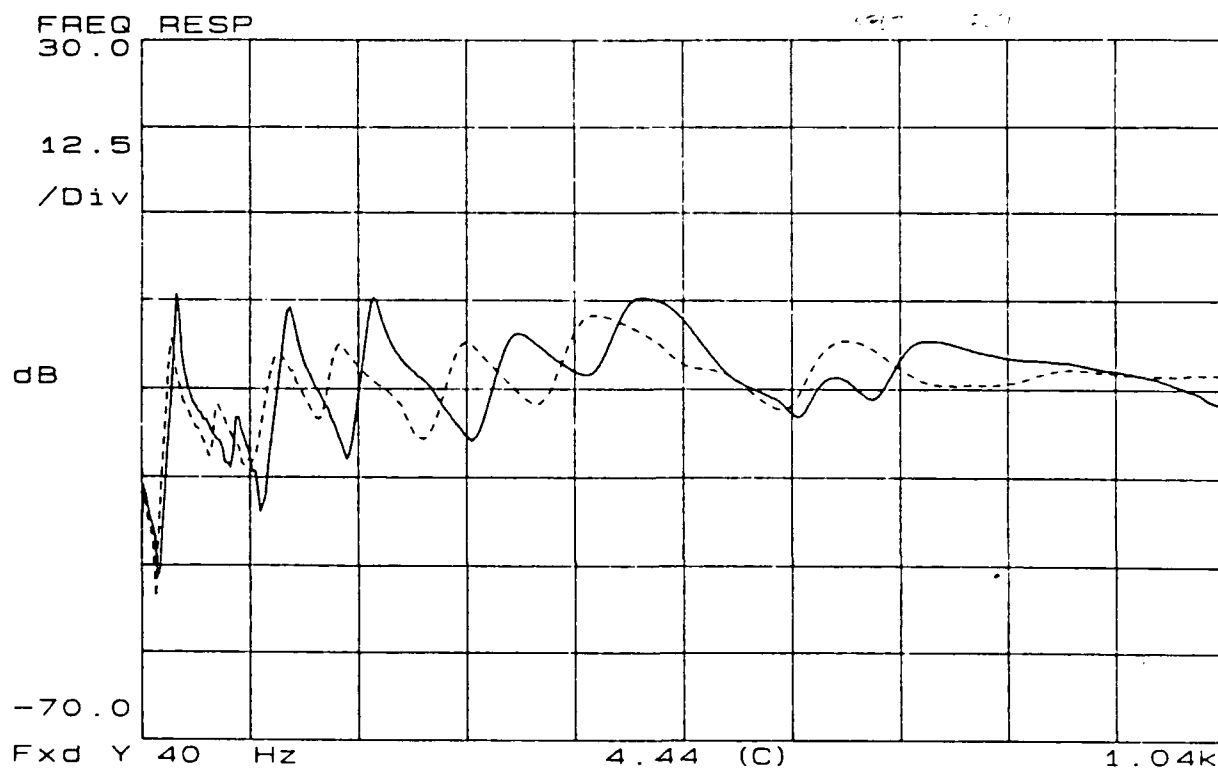


Figure 3.28. Comparison of Measured Frequency Responses of Spot and Line Weld Floating Element Plate at 4.44 °C.

[- - - - : Spot Welded, — : Line Welded]

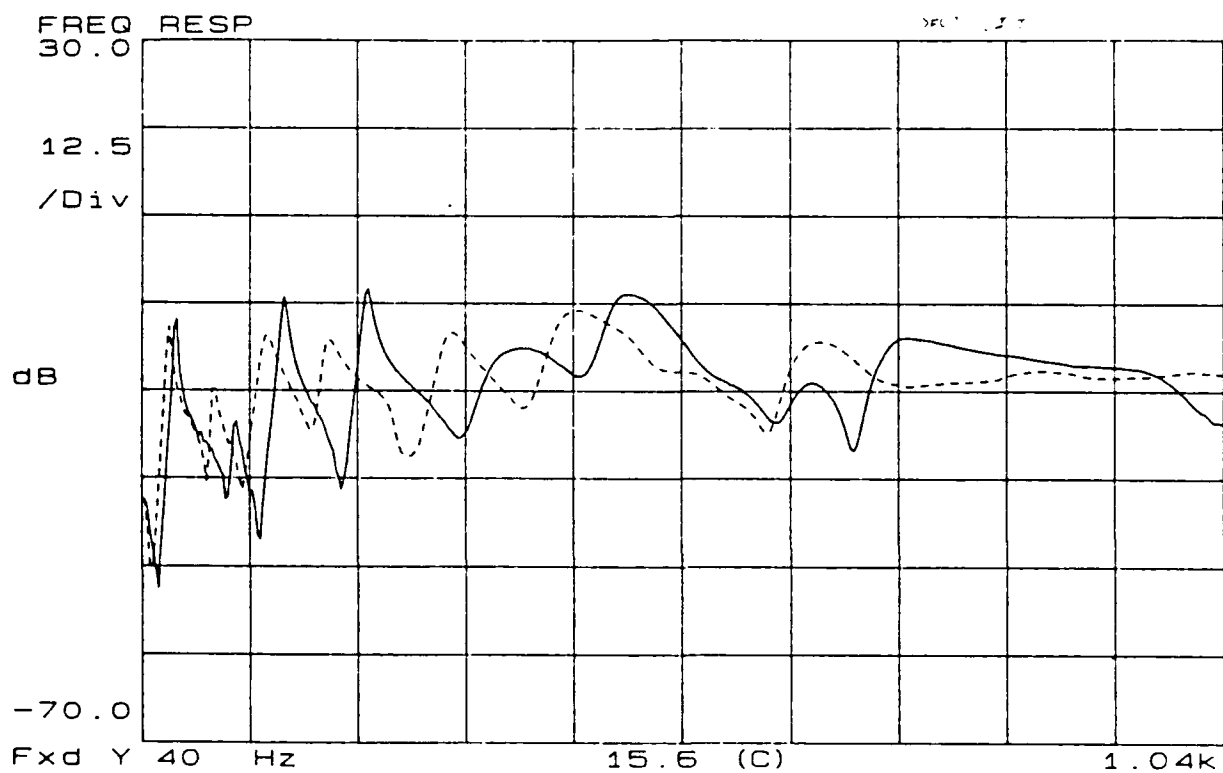


Figure 3.29. Comparison of Measured Frequency Responses of Spot and Line Welded Floating Element Plate at 15.6 °C.

[- - - - : Spot Welded, — : Line Welded]

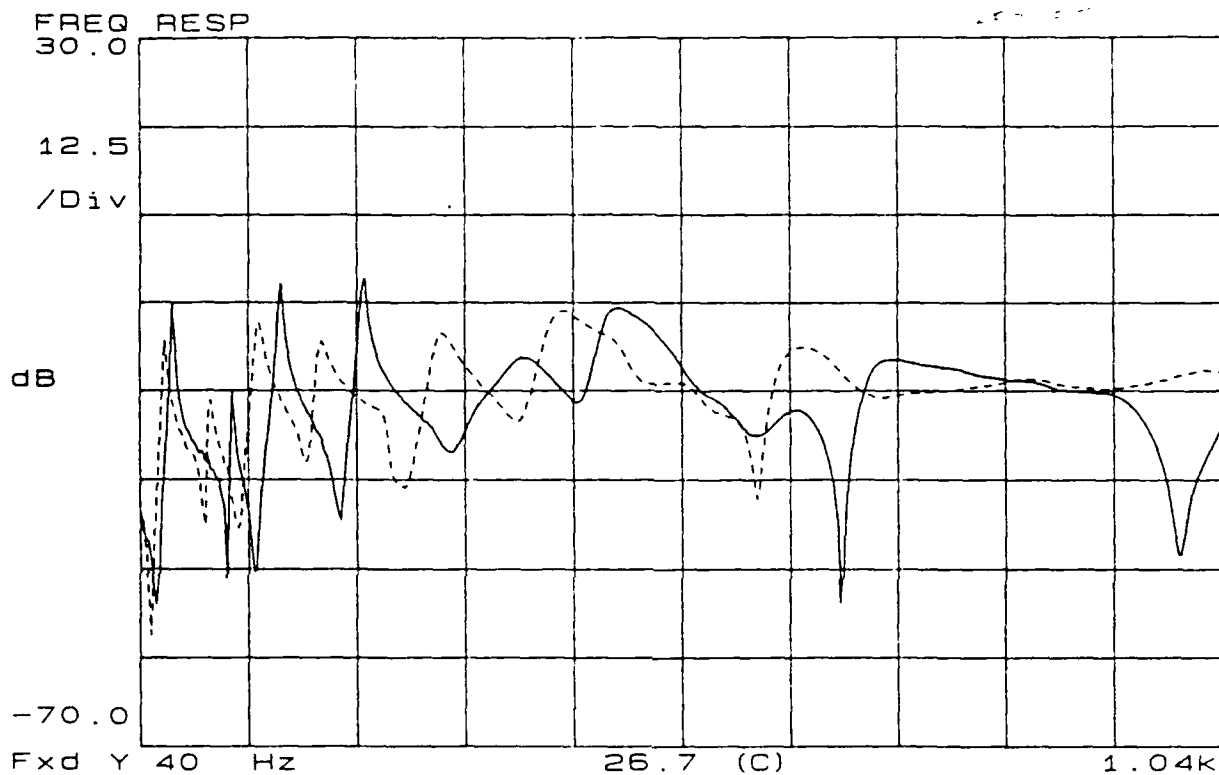


Figure 3.30. Comparison of Measured Frequency Responses of Spot and Line Welded Floating Element Plate at 26.7 °C.

[- - - - : Spot Welded, — : Line Welded]

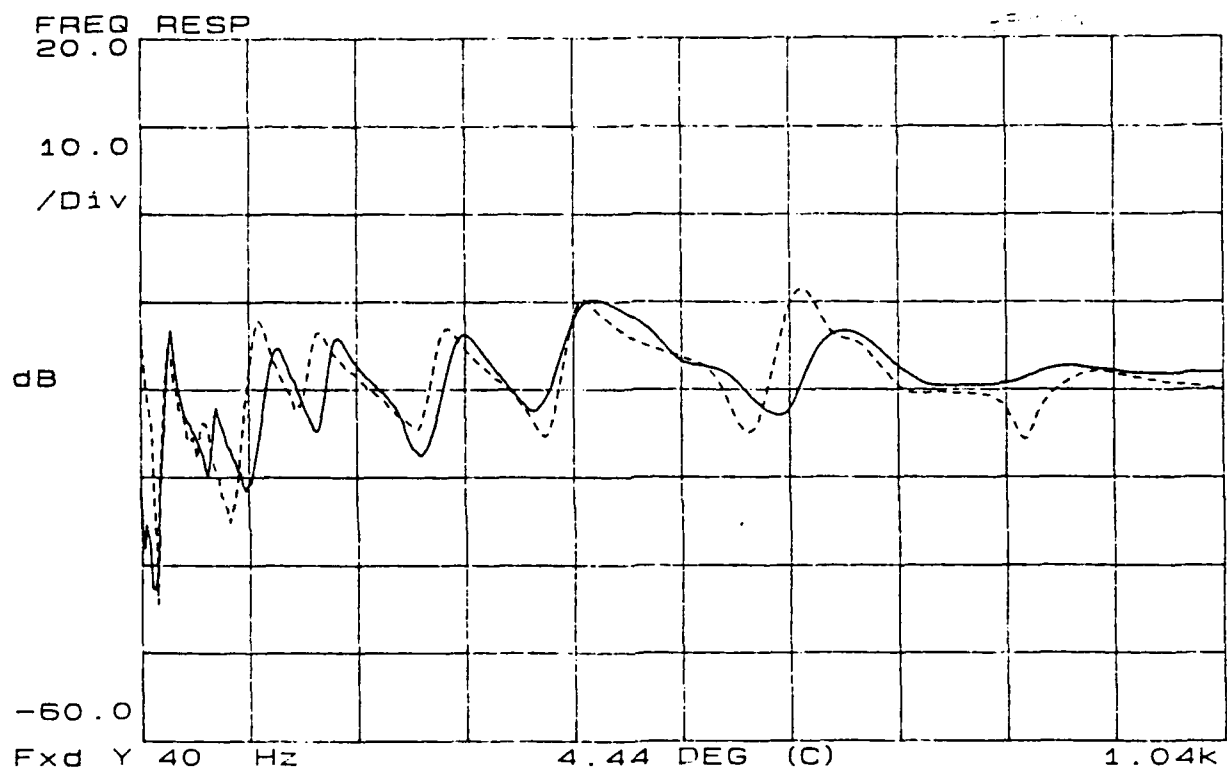


Figure 3.31. Comparison of Measured Frequency Response of Spot Welded Pocket Plate and Floating Element Plate at 4.44 °C.

[- - - - : Pocket Plate, — : Floating Element]

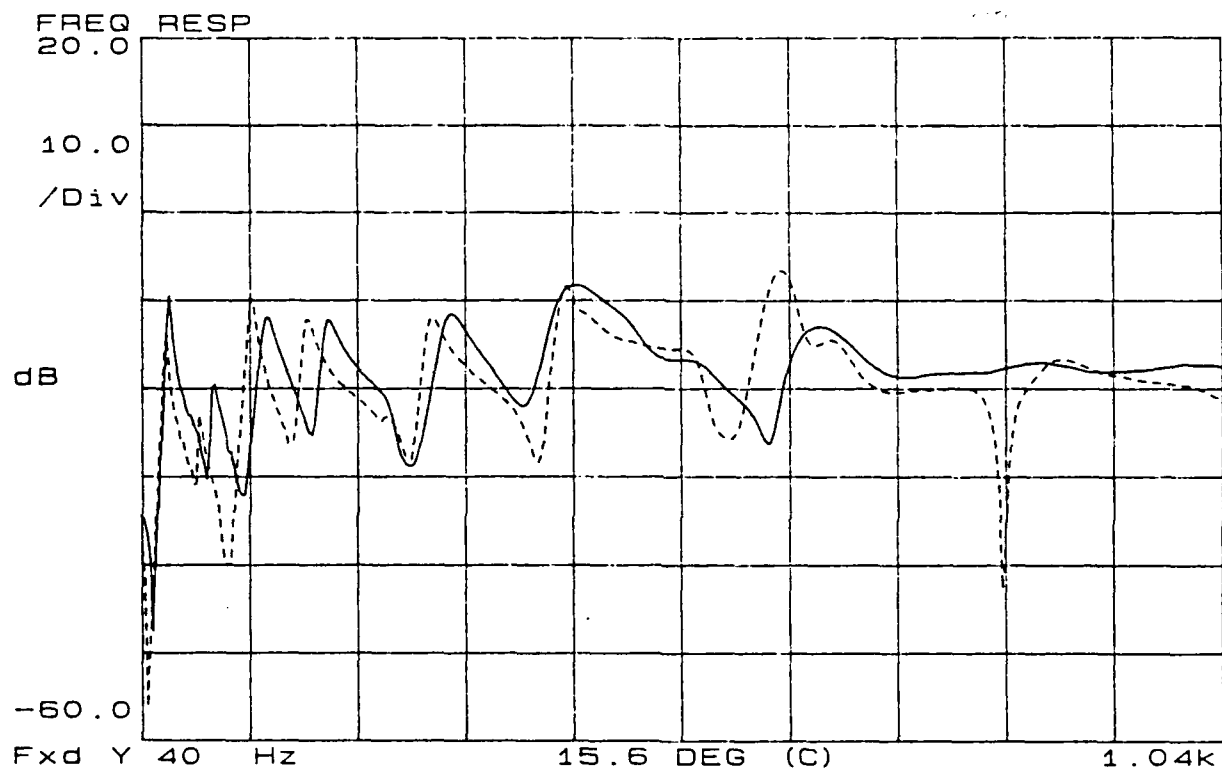


Figure 3.32. Comparison of Measured Frequency Response of Spot Welded Pocket Plate and Floating Element Plate at 15.6 °C.

[- - - - : Pocket Plate, — : Floating Element]

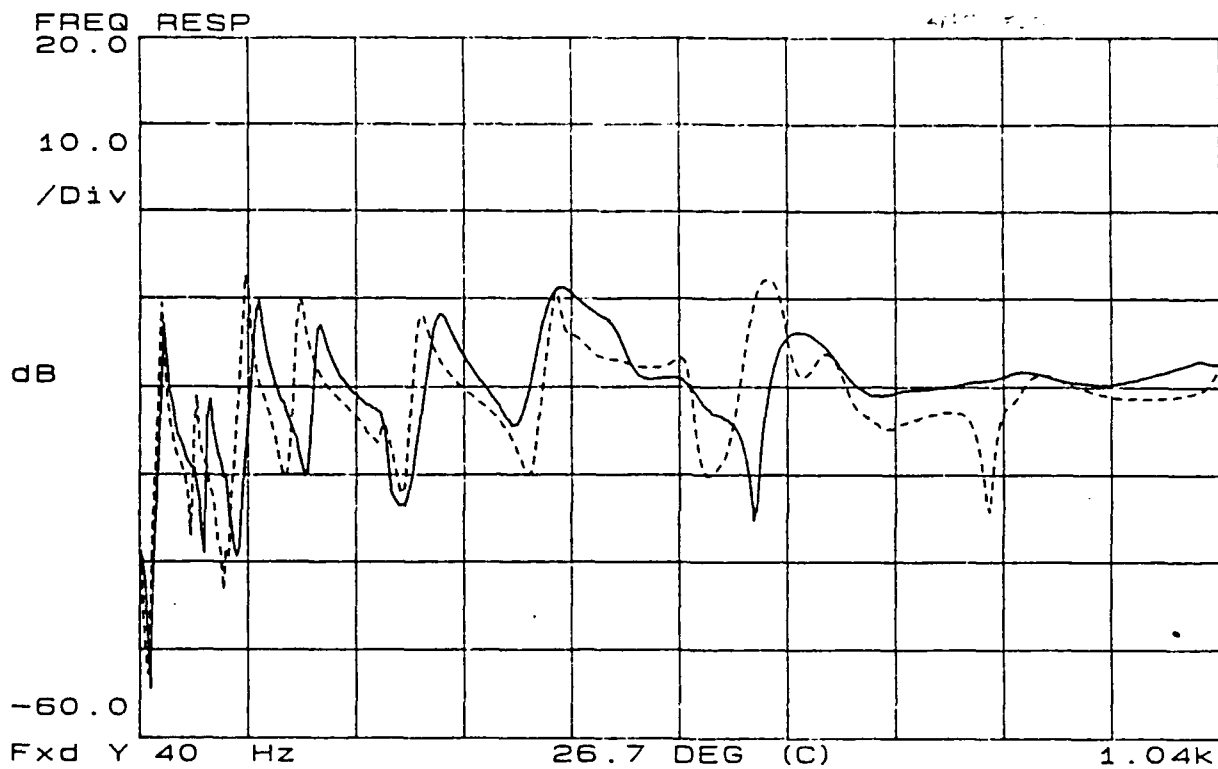


Figure 3.33. Comparison of Measured Frequency Responses of Spot Welded Pocket Plate and Floating Element Plate at 26.7 °C.

[- - - - : Pocket Plate, — : Floating Element]

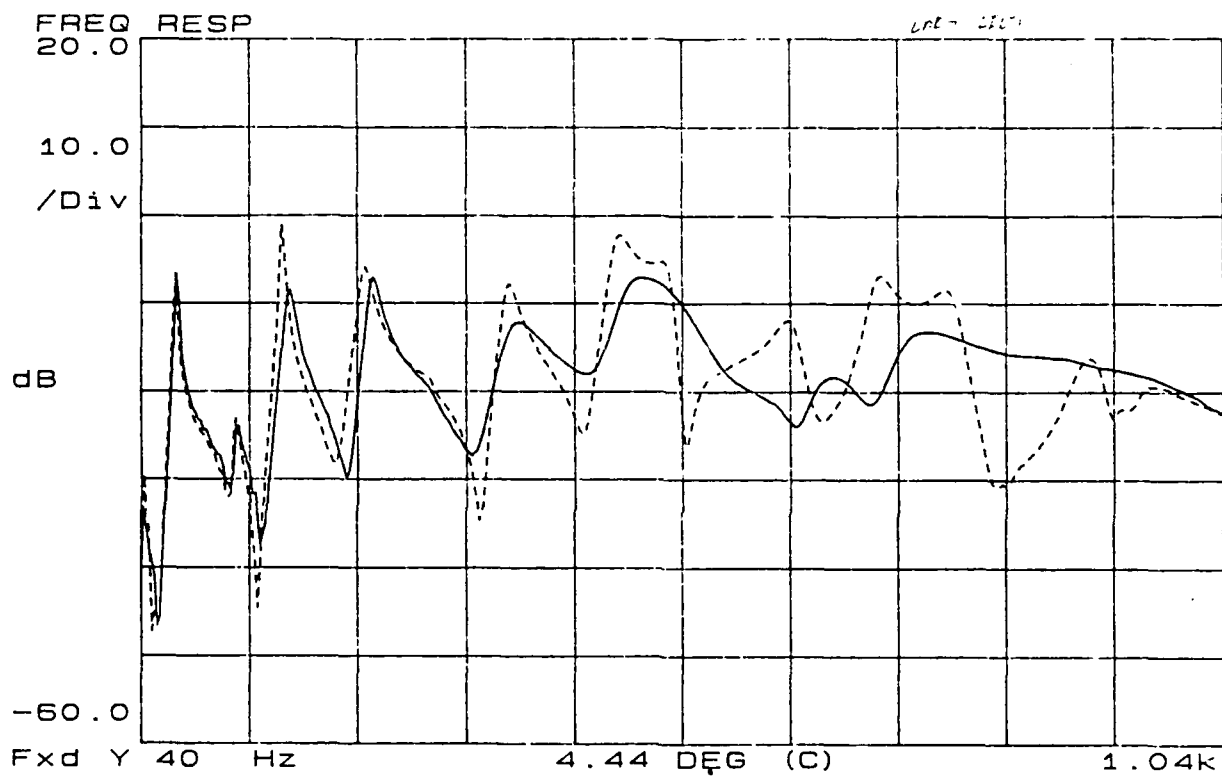


Figure 3.34. Comparison of Measured Frequency Response of Line Welded Pocket Plate and Floating Element Plate at 4.44 °C.

[- - - - : Pocket Plate, — : Floating Element]

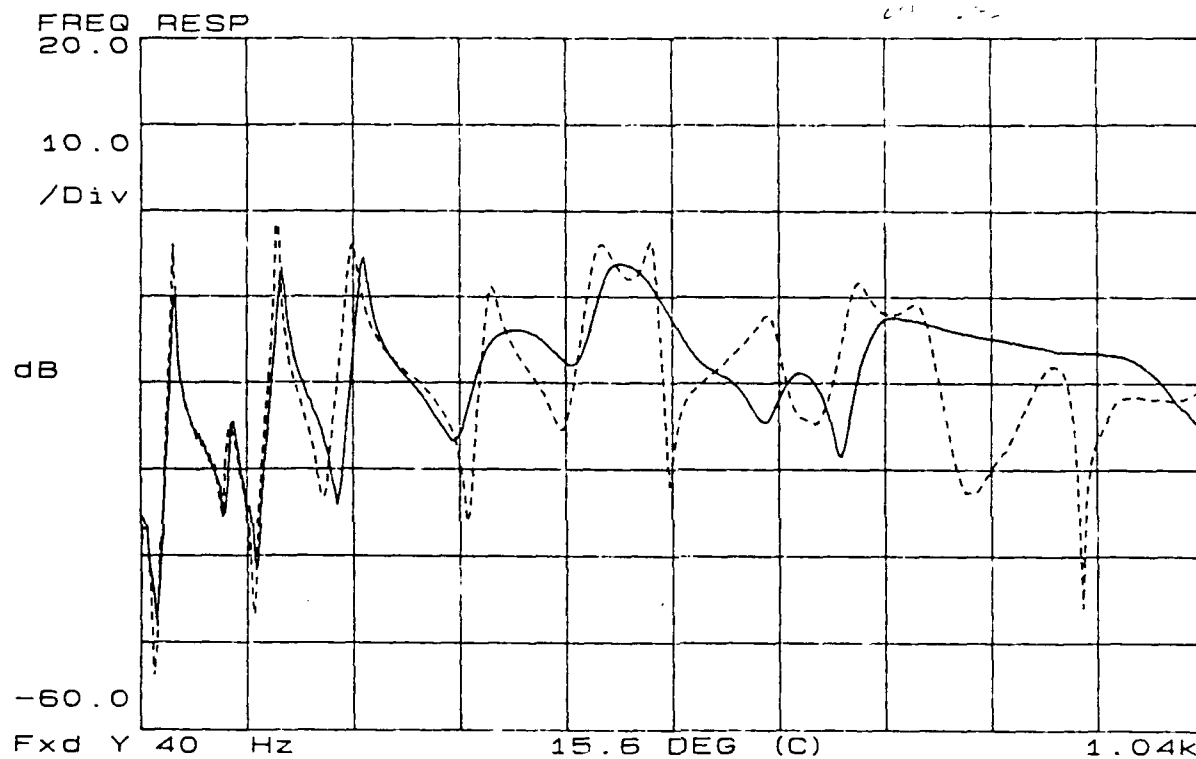


Figure 3.35. Comparison of Measured Frequency Response of Line Welded Pocket Plate and Floating Element Plate at 15.6 °C.

[- - - - : Pocket Plate, — : Floating Element]

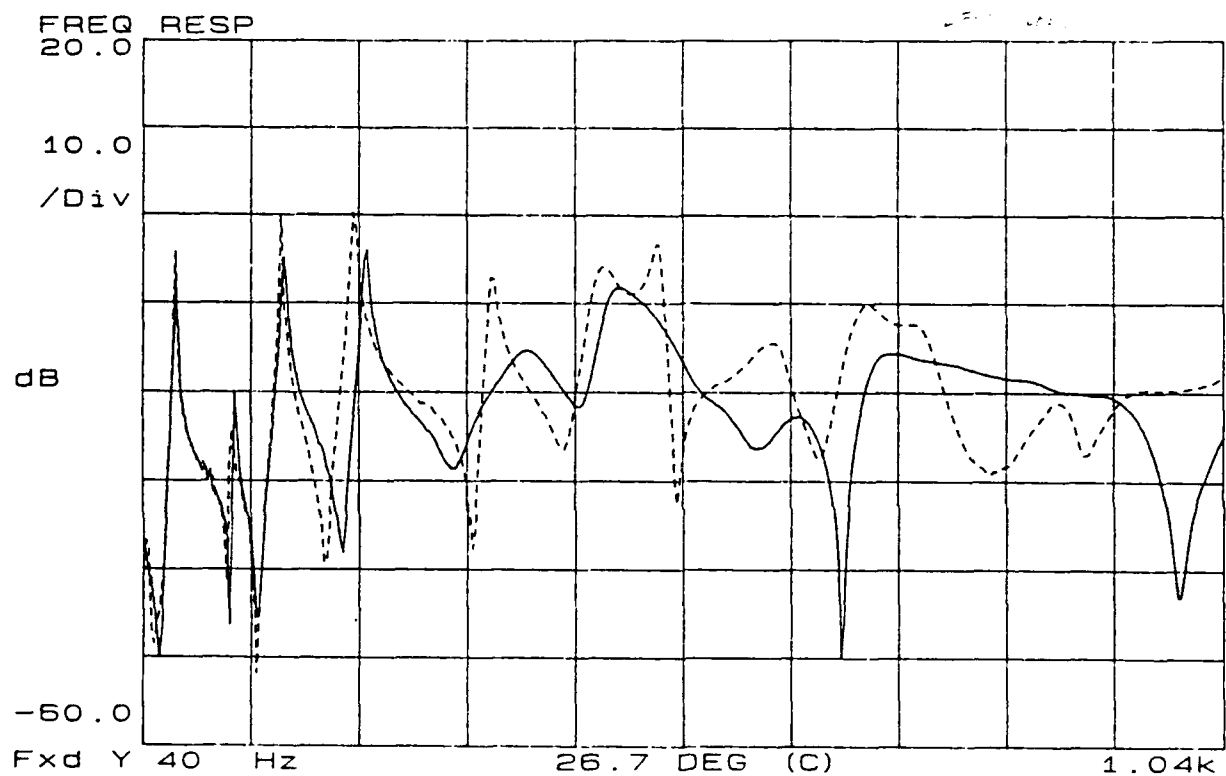


Figure 3.36. Comparison of Measured Frequency Responses of Line Welded Pocket Plate and Floating Element Plate at 26.7 °C.

[- - - - : Pocket Plate, — : Floating Element]

IV. FINITE ELEMENT ANALYSIS

A. POCKET PLATE RESULTS

A finite element representation of the pocket plate model is shown in Figure 4.1. The cover plate and base plate were modeled using the 4-node QUAD elements. The viscoelastic material and the structure surrounding it were modeled using 8-node HEXA elements. In the spot welded plate, a welded point is shared a single finite element node between cover plate and base structure. The other non-welded points that are corresponding to the same geometric point were belong to two different finite element nodes; one to cover plate and the other to base structure. In the continuous line welded plate all the welded point were shared the same finite element nodes.

Modal strain energy method was introduced to calculate the modal frequencies and modal loss factors. Five separate runs were conducted using the viscoelastic material properties of ISD-112 at 50, 200, 500, 800, and 1000 Hz, and at three temperatures to extract the normal modes. Using these reference frequencies we get a composite set of modal loss factors. In addition to the modal frequencies, the strain energy in the viscoelastic elements and the entire model were output from MSC/NASTRAN.

Since the shear modules of a viscoelastic material changes with frequency, it was necessary to estimate the actual modal frequencies of the damped plate using an interpolation procedure outlined by Johnson and

Kienholz [Ref. 7]. The first step of the interpolation process was to plot the shear modulus of ISD-112 versus frequency from 5 to 1000 Hz. Then, for the first mode, using NASTRAN results based on ISD-112 material properties at 50 Hz, the first modal frequency predicted by MSC/NASTRAN and the corresponding shear modulus were plotted. The same was then done using the first natural frequency predicted by normal mode extraction based on ISD-112 material properties at frequencies of 200, 500, 800, and 1000 Hz. A curve was then passed through these five points. The point where the MSC/NASTRAN modal frequencies for the first mode intersected the ISD-112 shear modulus curve was taken to be the interpolated modal frequency of the spot welded pocket plate configuration. A plot of the intersection of these two curves for the first 17 modes is shown in Figure 4.2.

Once the interpolated modal frequencies were found, the modal strain energy equations (2-5) and (2-6) were used to compute modal loss factors for the single layer configuration. A set of modal loss factors was computed based on the modal strain energies computed using viscoelastic properties at reference frequencies of 50, 200, 500, 800, and 1000 Hz. A set of composite modal loss factors for the modal frequencies near these reference frequencies was then selected. The resulting modal loss factors are shown in Table 4.1 and are plotted versus frequency in Figure 4.3. As seen in Figure 4.3, the modal strain energy method is predicting high damping for this configuration with an average modal loss factor of 0.132.

Using the set of composite modal loss factors, the frequency response of the damped plate was computed using MSC/NASTRAN. Modal damping was introduced to the model using the SDAMP option in the Case Control Deck and the TABDMP1 damping table in the Bulk Data Deck as described in the MSC/NASTRAN Handbook for Dynamic Analysis [Ref. 8]. Since MSC/NASTRAN uses a linear interpolation between points in the damping table to describe the modal damping in the model [Ref. 8], a simple curve fit was applied to the set of composite modal loss factors as shown in Figure 4.3. Points from this curve fit were then used in the MSC/NASTRAN damping table. To compute the frequency response, a unit excitation force was applied at the same node as the undamped plate, and the node used for the response was also the same as the undamped plate [Ref. 2].

1. Spot Welded Pocket Plate Results

These loss factors for spot welded pocket plate based on 4.44 °C (40 °F), 15.6 °C(60 °F), and 26.7 °C (80 °F) are listed in Table 4.1. The estimated loss factor versus frequency are shown in Figure 4.4. The damping values used for the frequency response calculation in MSC/NASTRAN came from a curve-fit to the set of composite modal loss factors.

The results of the frequency response calculations are shown in Figures 4.5, through 4.7. The dashed line represents the undamped reference plate, and the solid line represents the modal frequency response of the spot welded

pocket plate configuration. Material properties at 200 Hz were used for the ISD-112 damping material. The first thirty modes were used in the modal summation for the response. A listing of the MSC/NASTRAN data deck used to compute the modal frequency response is in Appendix D.

The modal loss factors estimated using the modal strain energy method are compared to those measured experimentally for the spot welded pocket plate in Figure 4.8. The estimated loss factors are greater than the experimentally determined loss factors throughout the spectrum of interest, and especially in the middle frequencies.

The frequency response of the spot welded pocket plate is compared to the experimentally measured frequency response are shown in Figures 4.9, through 4.11. The comparison was accomplished by normalizing both the experimentally determined frequency response and the frequency response computed by MSC/NASTRAN. Both responses were normalized using a value of $1.0 \frac{\text{in/sec}^2}{\text{lb}}$. The effects of the greater loss factors estimated by the modal strain energy method are obvious as the level of the predicted response is lower than the measured response. The shift in frequency between the two curves is due to the finite element model being inherently stiffer than the actual system. The correlation between the two curves is especially good below 250 Hz as this is where the differences between estimated and measured modal loss factors are the least.

**TABLE 4.1. ESTIMATED MODAL LOSS FACTORS FOR THE SPOT
WELDED POCKET PLATE AT 4.44/15.6/26.7 °C.**

4.44 °C (60 °F)		15.6 °C (60 °F)		26.7 °C (80 °F)	
<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>
68.2	0.063	67.0	0.046	66.0	0.025
110.7	0.056	109.0	0.034	107.8	0.018
169.4	0.117	162.0	0.091	158.0	0.053
224.3	0.090	217.5	0.063	213.8	0.036
307.7	0.140	295.0	0.091	287.0	0.047
346.6	0.103	333.0	0.047	324.5	0.055
472.1	0.116	453.0	0.070	441.9	0.049
498.5	0.112	477.0	0.093	460.1	0.073
507.2	0.160	511.0	0.113	463.5	0.064
541.7	0.163	588.0	0.104	490.9	0.078
611.1	0.133	625.0	0.086	571.0	0.055
647.1	0.122	668.0	0.089	609.1	0.048
685.9	0.087	713.0	0.077	651.0	0.055
732.4	0.112	831.0	0.077	698.7	0.042
856.7	0.096	834.0	0.065	814.4	0.042
860.9	0.098	868.0	0.051	820.6	0.034
898.7	0.040			852.7	0.031

2. Line Welded Pocket Plate Results

The estimated loss factors for the line welded pocket plate based on 4.44 °C (40 °F), 15.6 °C (60 °F), and 26.7°C (80 °F) are listed in Table 4.2 and are plotted versus frequency shown in Figure 4.12. The estimated loss factors for line welded pocket plate also give good damping. The modal frequency response of the line welded pocket plate were computed using the first 30 modes and viscoelastic material properties at 200 Hz. The results of the frequency response calculations are shown in Figures 4.13, through 4.15. The dashed line represents the undamped reference plate, and the solid line represents the frequency response of the line welded pocket plate. The modal loss factors estimated using the modal strain energy method are compared to those measured experimentally for the line welded pocket plate configuration in Figure 4.16. The estimated loss factors are greater than the experimentally measured loss factors throughout the spectrum of interest, and especially in the middle frequencies.

The frequency response of the line welded pocket plate is compared to the experimentally measured frequency response in Figures 4.17, through 4.19. The correlation between the two curves is especially good below 250 Hz as this is where the differences between estimated and measured modal loss factors are the least. The comparison of estimated spot and line welded pocket plate at 4.44 °C (40 °F), 15.6 °C (60 °F), and 26.7°C (80 °F) are shown in Figures 4.20, through 4.22. As can be seen from the figure, the spot welded pocket plate is more damped than line welded pocket plate. The reason is the

line welded pocket plate was more constrained than spot welded one that make it hard to deform to get more shear than less damped ,less loss factor increase. From Figure 4.4 and Figure 4.12, we can see both the three lines have similar trend that loss factor increase to the peak at frequency about 500 Hz. Lower the temperature the viscoelastic material gets stiffer that increase the damped effect. So, the lowest reference temperature (4.44 °C) plate has highest modal loss factor .On the other hand the highest reference temperature (26.7 °C) plate has the lowest modal loss factor. The same trend was shown in the experimental measurements.

**TABLE 4.2. ESTIMATED MODAL LOSS FACTORS FOR THE LINE
WELDED POCKET PLATE AT 4.44/15.6/26.7 °C.**

4.44 °C (60 °F)		15.6 °C (60 °F)		26.7 °C (80 °F)	
<u>f (Hz)</u>	<u>n</u>	<u>f (Hz)</u>	<u>n</u>	<u>f (Hz)</u>	<u>n</u>
70.6	0.020	70.2	0.012	70.0	0.006
122.8	0.008	122.6	0.005	122.4	0.003
179.4	0.058	176.1	0.040	174.0	0.022
249.7	0.030	247.2	0.024	245.5	0.014
323.3	0.089	314.6	0.058	309.4	0.030
388.1	0.044	381.0	0.042	376.0	0.028
491.3	0.084	477.2	0.060	469.2	0.033
545.2	0.060	533.9	0.054	525.2	0.034
546.7	0.064	534.6	0.038	528.8	0.020
585.8	0.072	571.2	0.054	562.0	0.033
661.5	0.067	644.6	0.054	633.3	0.037
690.9	0.084	669.8	0.061	658.2	0.033
731.6	0.061	714.4	0.050	703.5	0.031
800.4	0.079	776.7	0.059	762.7	0.036
881.3	0.054	864.6	0.034	855.7	0.019
944.7	0.052	925.7	0.038	914.7	0.023
		944.3	0.044	932.0	0.024

B. FLOATING ELEMENT PLATE RESULTS

The base plate and cover plate were modeled using the 4-node QUAD elements. The two viscoelastic material, an aluminum plate between two viscoelastic material, and the structure surrounding it were modeled using 8-node HEXA elements. In the spot welded floating element plate, a welded point is shared a single finite element node between cover plate and base structure, the other non-welded points that are corresponding to the same geometric point were belong to two different finite element nodes; one to cover plate and the other to base structure. In the continuous line welded floating element all the welded point were shared the same finite element nodes. A finite element representation of the floating element plate model is shown in Figure 4.23.

Modal strain energy method was used to calculate the modal frequencies and modal loss factors. We use viscoelastic material at 50, 200, 500, 800, and 1000 Hz to extract the normal mode. Using these reference frequencies we get a composite set of modal loss factors.

1. Spot Welded Floating Element Results

The estimated loss factors for spot welded floating element plate based on 4.44 °C (40 °F), 15.6 °C (60 °F), and 26.7 °C (80 °F) are listed in Table 4.3. The

loss factor versus frequency are shown in Figure 4.24. The results of the modal frequency response calculations are shown in Figures 4.25, through 4.27. The dashed line represents the undamped reference plate, and the solid line represents the frequency response of the spot welded floating element plate. The modal loss factors estimated using the modal strain energy method are compared to those measured experimentally for the spot welded pocket plate configuration in Figure 4.28. The estimated loss factors are greater than the experimentally determined loss factors throughout the spectrum of interest, and especially in the middle frequencies.

The frequency response of the spot welded floating element configuration is compared to the experimentally measured frequency response in Figures 4.29, through 4.31. The correlation between the two curves is especially good below 250 Hz as this is where the differences between estimated and measured modal loss factors are the least.

**TABLE 4.3. ESTIMATED MODAL LOSS FACTORS FOR THE SPOT
WELDED FLOATING ELEMENT AT 4.44/15.6/26.7 °C.**

4.44 °C (60 °F)		15.6 °C (60 °F)		26.7 °C (80 °F)	
<u>f (Hz)</u>	<u>n</u>	<u>f (Hz)</u>	<u>n</u>	<u>f (Hz)</u>	<u>n</u>
67.9	0.080	66.1	0.065	64.7	0.045
106.7	0.093	103.6	0.062	101.7	0.036
167.9	0.139	158.9	0.108	153.7	0.066
217.8	0.114	209.5	0.086	204.1	0.051
300.0	0.177	283.6	0.115	272.2	0.054
341.9	0.141	326.9	0.104	314.5	0.054
468.4	0.148	444.8	0.105	430.9	0.066
483.3	0.130	455.9	0.145	437.5	0.077
489.9	0.193	461.5	0.096	448.5	0.058
525.0	0.187	490.4	0.140	470.2	0.082
592.1	0.161	559.8	0.112	541.6	0.063
659.2	0.139	629.0	0.088	613.6	0.045
678.2	0.107	651.0	0.083	634.1	0.053
707.7	0.140	672.9	0.096	654.4	0.054
859.2	0.111	826.3	0.069	809.5	0.039
870.0	0.100	839.0	0.066	822.1	0.040
872.8	0.102	842.8	0.060	827.7	0.035

2. Line Welded Floating Element Plate Results

The estimated loss factors for line welded pocket plate based on 4.44 °C (40 °F), 15.6 °C (60 °F), and 26.7 °C (80 °F) are listed in Table 4.4 and are plotted versus frequency in Figure 4.30. The results of the modal frequency response calculations are shown in Figures 4.31, Figure 4.31, through 4.33. The dashed line represents the undamped reference plate, and the solid line represents the frequency response of line spot welded floating element configuration. The modal frequency response of the line welded floating element configuration is compared to the experimentally measured frequency response in Figures 4.34, through 4.36. The correlation between the two curves is especially good below 250 Hz as this is where the differences between estimated and measured modal loss factors are the least.

The comparison of estimated spot and line welded pocket plate at 4.44 °C (40 °F), 15.6 °C (60 °F), and 26.7 °C (80 °F) are shown in Figures 4.36, through 4.38. As can be seen from the figure, the spot welded floating element plate is more damped than line welded floating element. The reason is the line welded floating element was more constrained than spot welded one that make it hard to deform to get more shear than less damped, less loss factor increase. From Fig 4.24, Fig 4.32, we can see both the three lines have similar trend that loss factor increase to the peak at frequency about 500 Hz. Lower the temperature the viscoelastic material gets stiffer that increase the damped effect. So, the lowest reference temperature (4.44°C) plate has highest

modal loss factor .On the other hand the highest reference temperature (26.7°C) plate has the lowest modal loss factor.

TABLE 4.4. ESTIMATED MODAL LOSS FACTORS FOR THE LINE WELDED FLOATING ELEMENT AT 4.44/15.6/26.7 °C.

4.44 °C (60 °F)		15.6 °C (60 °F)		26.7 °C (80 °F)	
<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>	<u>f (Hz)</u>	<u>η</u>
70.6	0.036	69.8	0.035	68.9	0.032
121.3	0.048	119.7	0.040	118.3	0.027
178.6	0.080	173.6	0.063	170.1	0.041
247.1	0.061	242.0	0.052	238.2	0.035
322.1	0.119	310.4	0.079	303.3	0.043
383.8	0.070	373.0	0.065	365.4	0.044
491.3	0.113	472.4	0.079	461.8	0.044
534.4	0.089	518.0	0.066	507.7	0.041
541.5	0.091	523.7	0.073	512.2	0.045
570.5	0.103	549.7	0.081	536.2	0.052
643.5	0.110	619.0	0.084	603.0	0.054
693.3	0.114	666.3	0.075	652.3	0.040
726.9	0.086	703.6	0.066	689.7	0.040
774.6	0.103	745.3	0.075	728.1	0.046
897.1	0.087	870.4	0.052	856.9	0.029
939.9	0.087	910.1	0.058	891.2	0.034
944.1	0.075	917.8	0.052	903.4	0.031

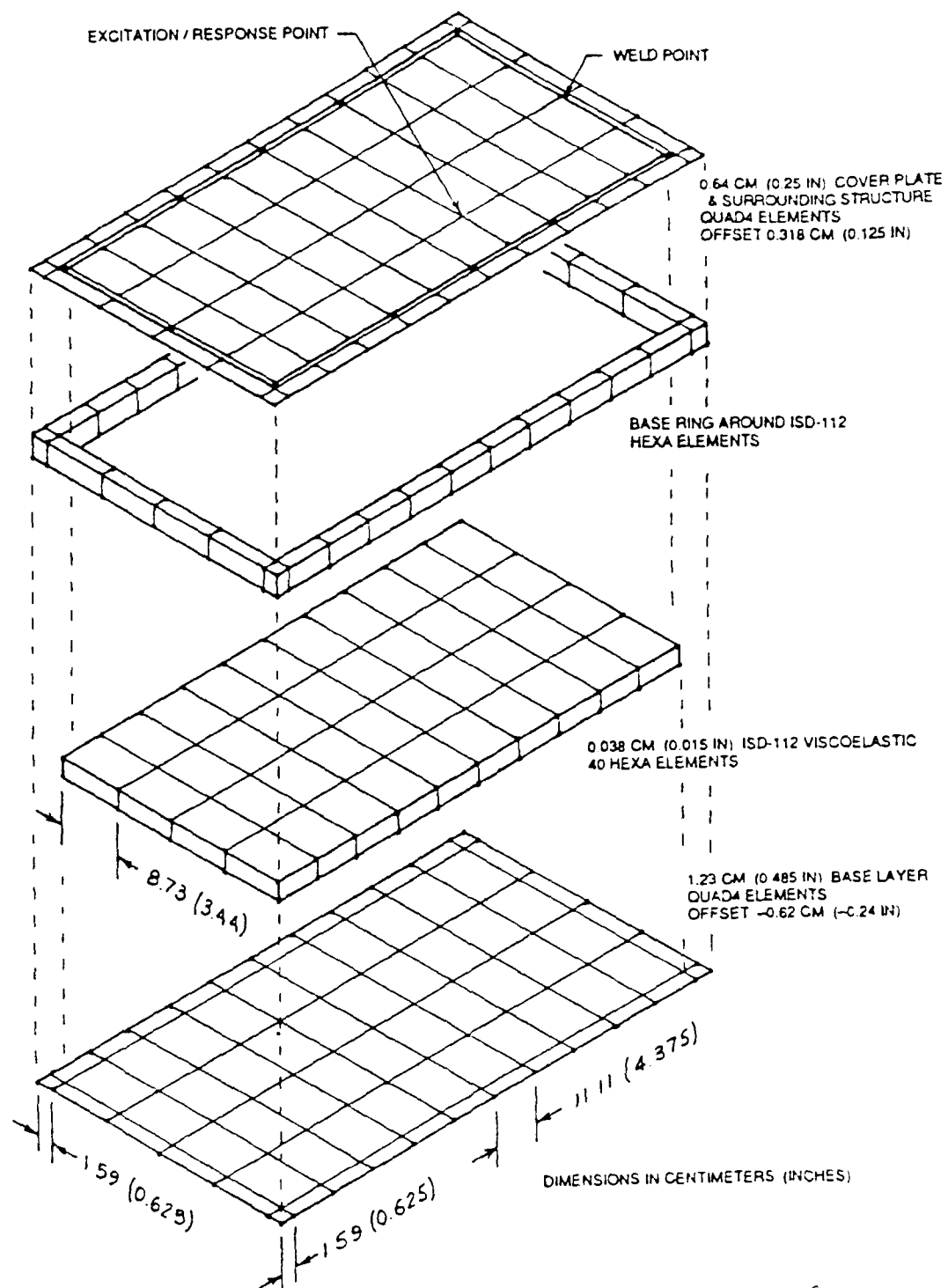


Figure 4.1. Finite Element Representation of the Pocket Plate Configuration.

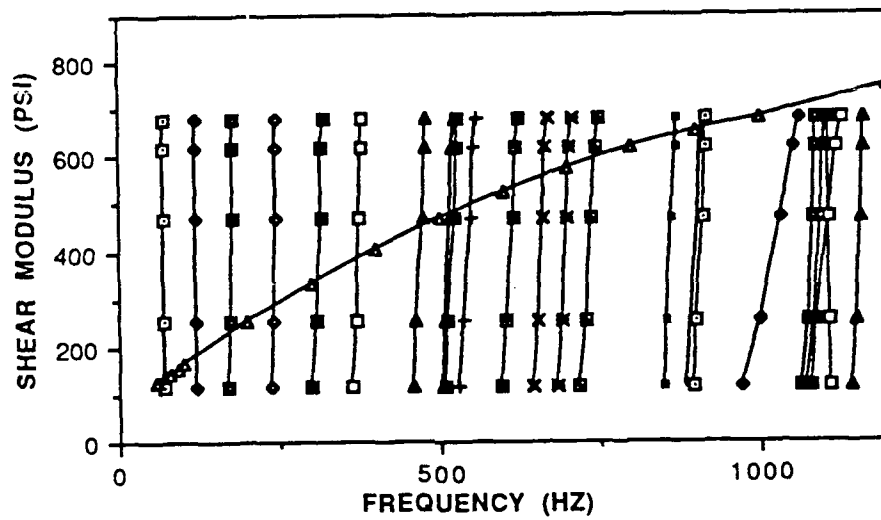


Figure 4.2. Interpolation of the Modal Frequencies for the Spot Welded Floating Element Configuration

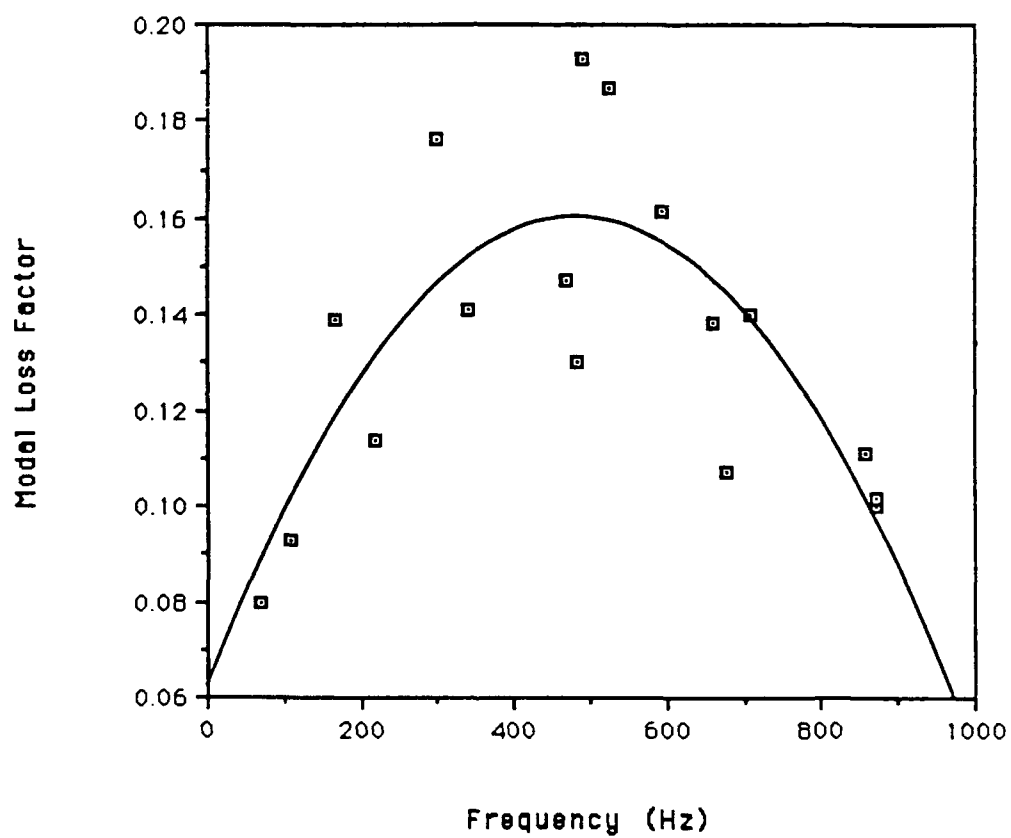


Figure 4.3. Estimated Modal Loss Factors for the Spot Welded Floating Element Configuration with the Curve Fit Used for the MSC/NASTRAN Damping Table.

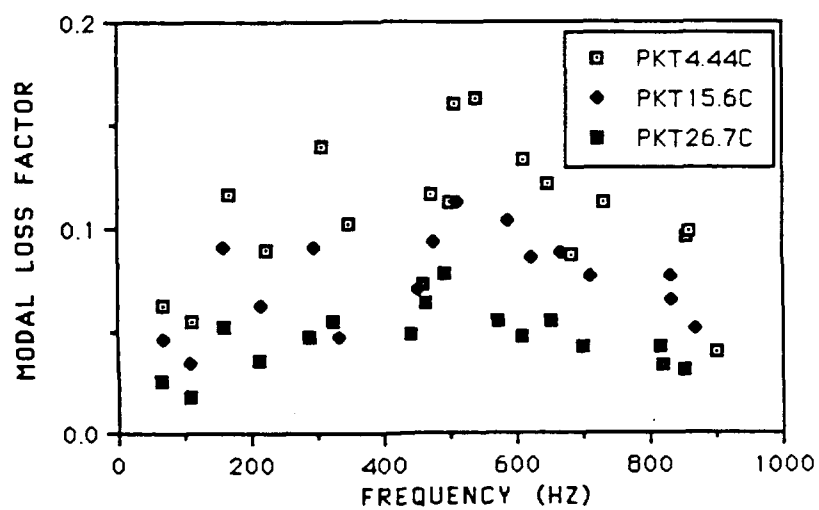


Figure 4.4. Estimated Modal Loss Factor for Spot Welded Pocket Plate at 4.44/15.6/26.7 °C.

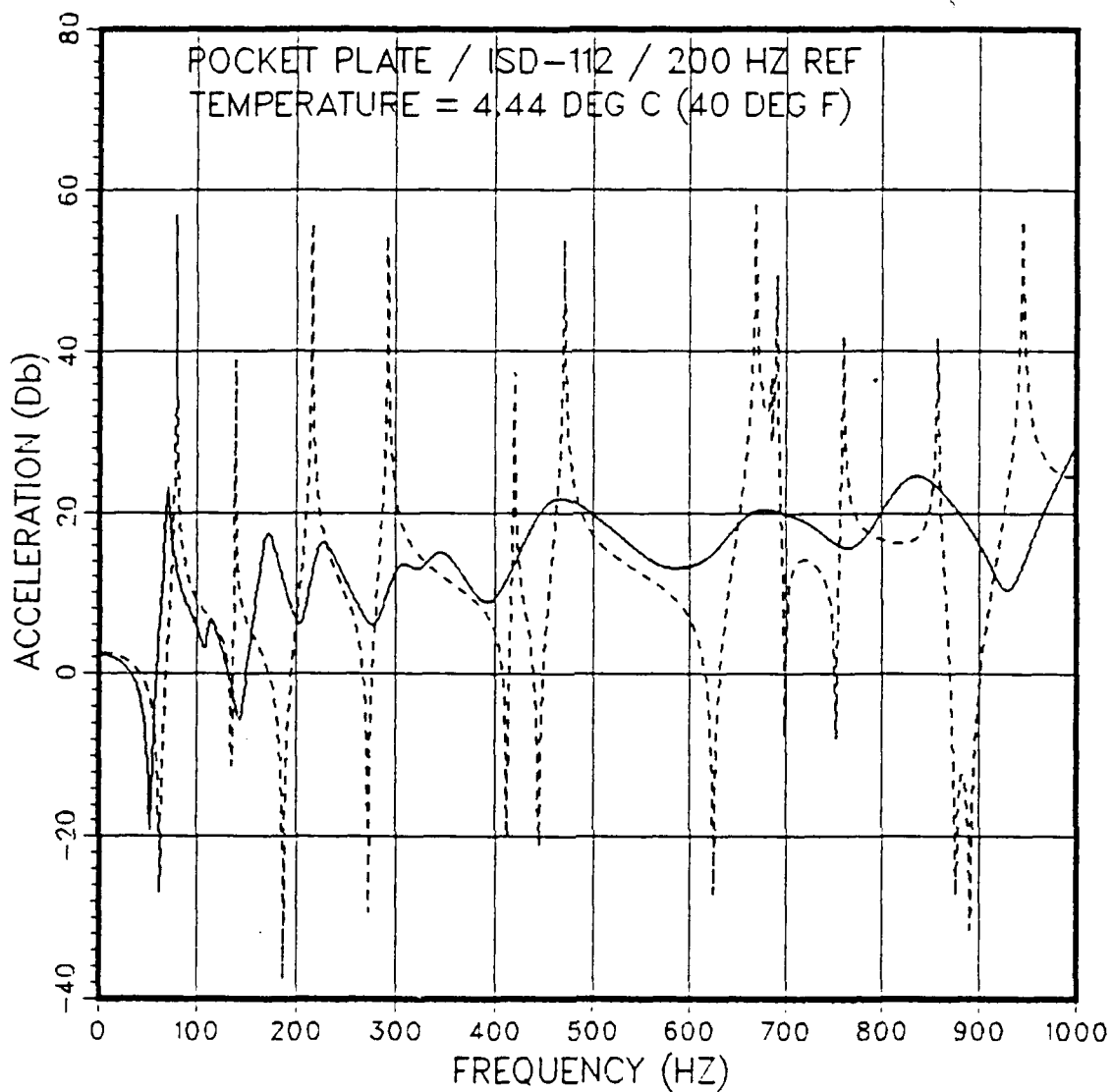


Figure 4.5. Calculated Frequency Response of the Spot Welded Pocket Plate at 4.44 °C.

[- - - - : reference plate , — : spot welded pocket plate]

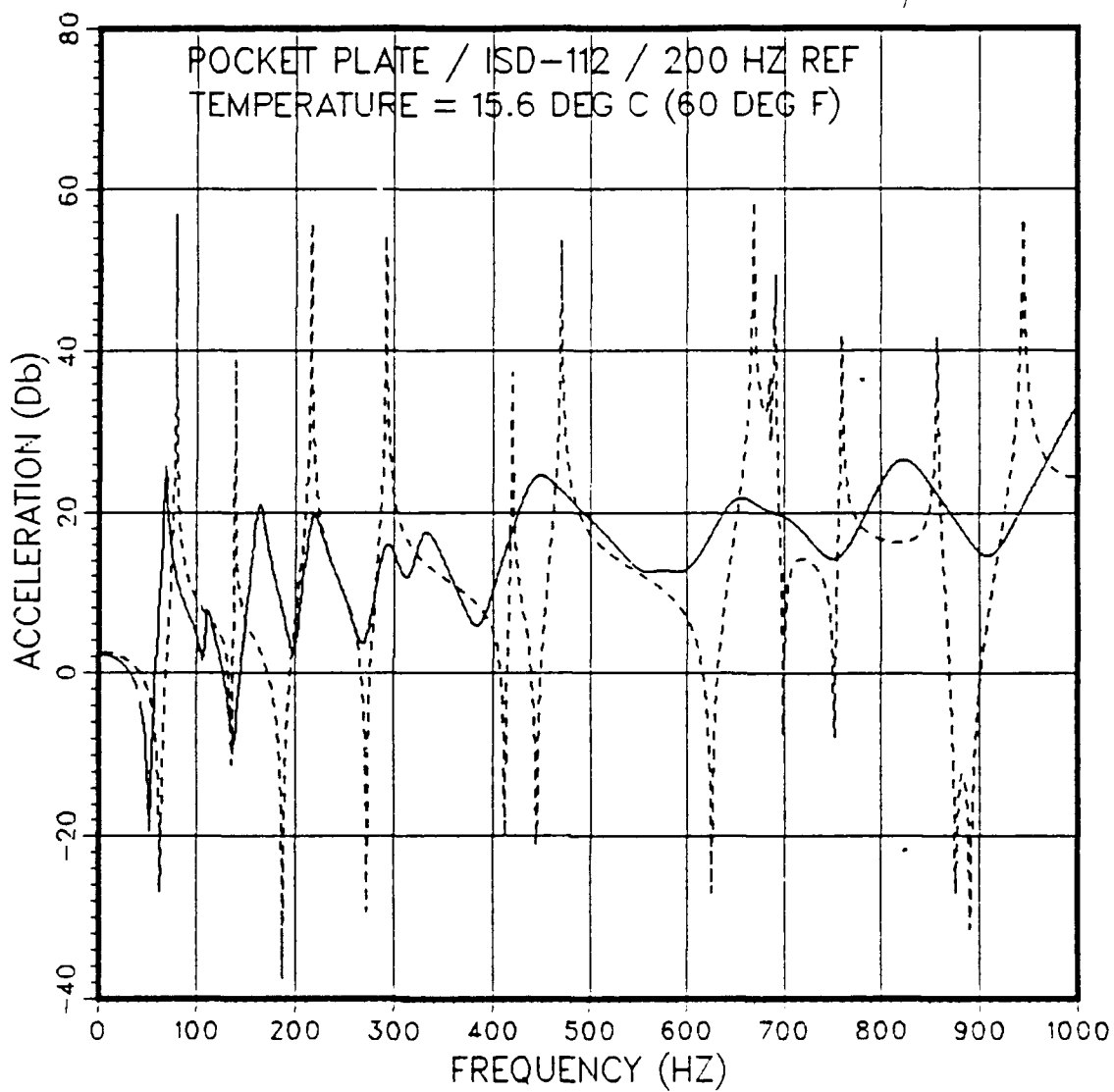


Figure 4.6. Calculated Frequency Response of the Spot Welded Pocket Plate at 15.6 °C.

[- - - - : reference plate , — : spot welded pocket plate]

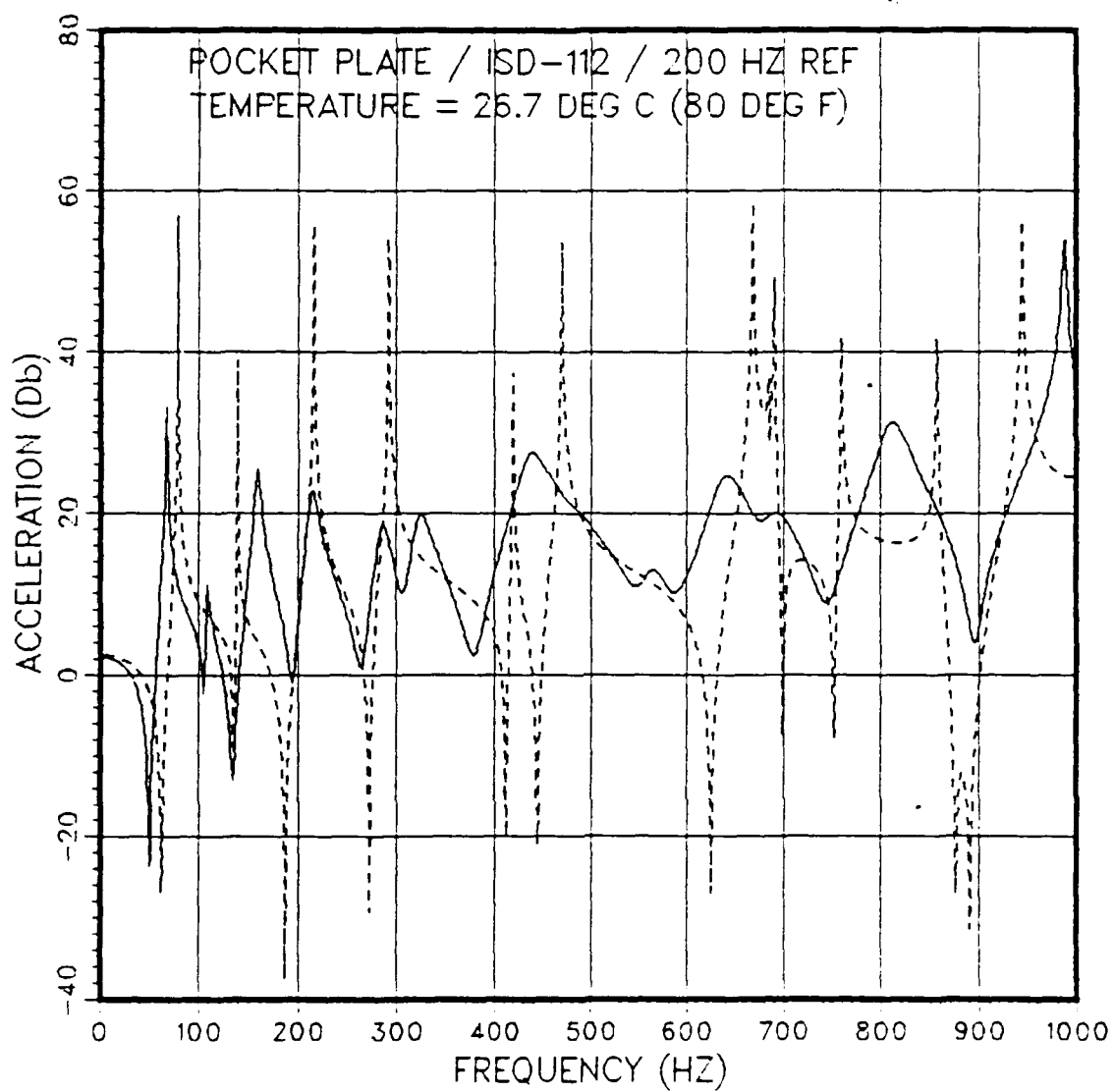


Figure 4.7. Calculated Frequency Response of the Spot Welded Pocket Plate at 26.7 °C.

[- - - - : reference plate , — : spot welded pocket plate]

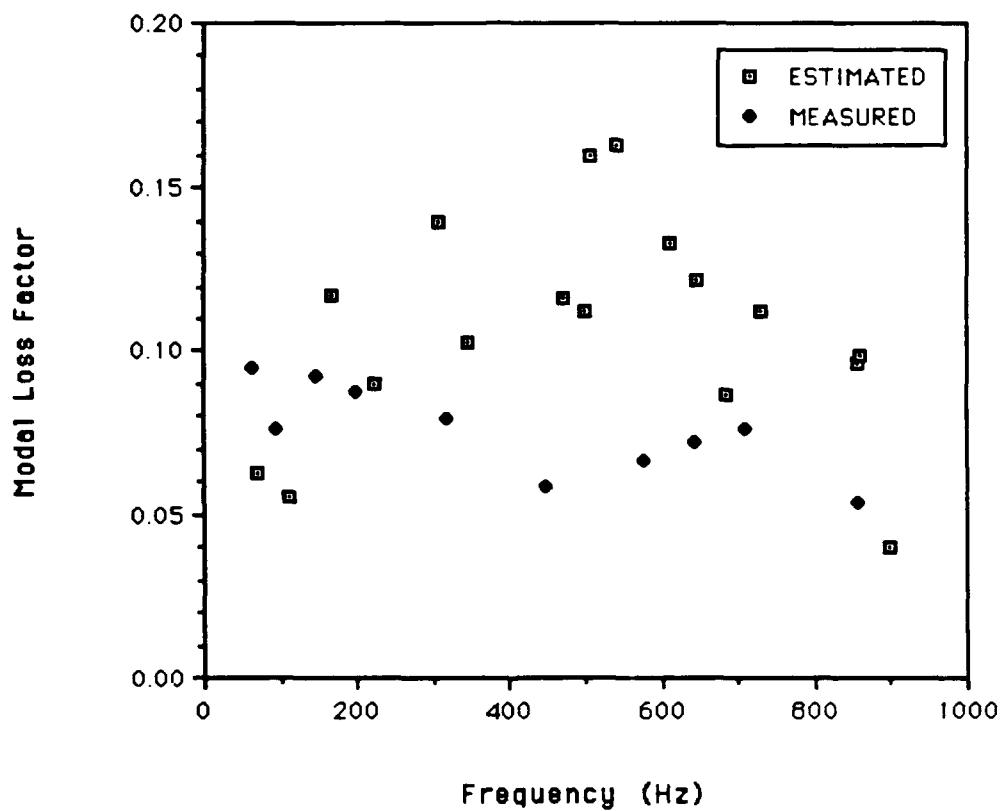


Figure 4.8. Comparison of Estimated and Measured Modal Loss Factors for Spot Welded Pocket Plate at 4.44 °C.

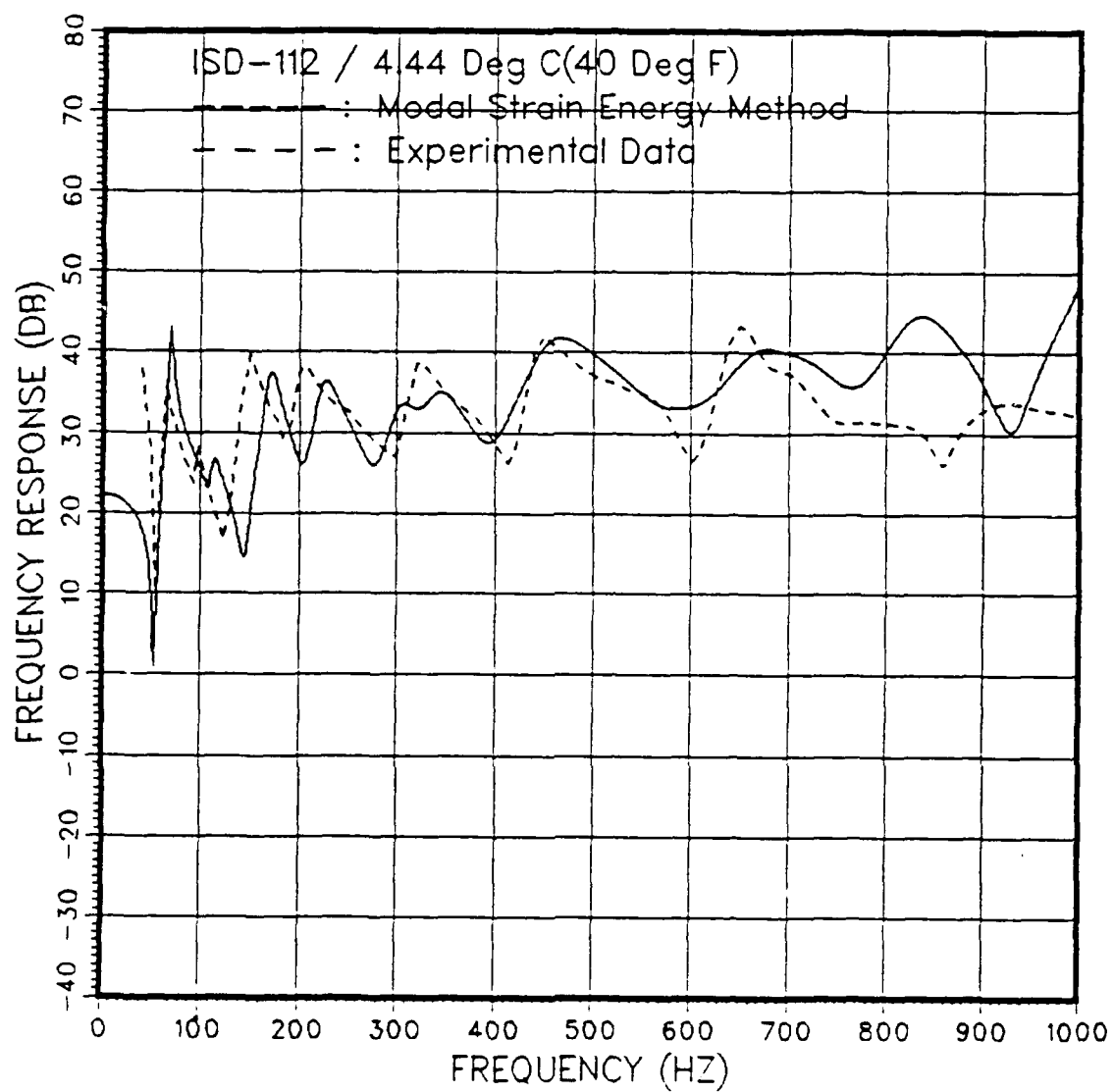


Figure 4.9. Comparison of Estimated and Measured Frequency Response for the Spot Welded Pocket Plate at 4.44 °C.

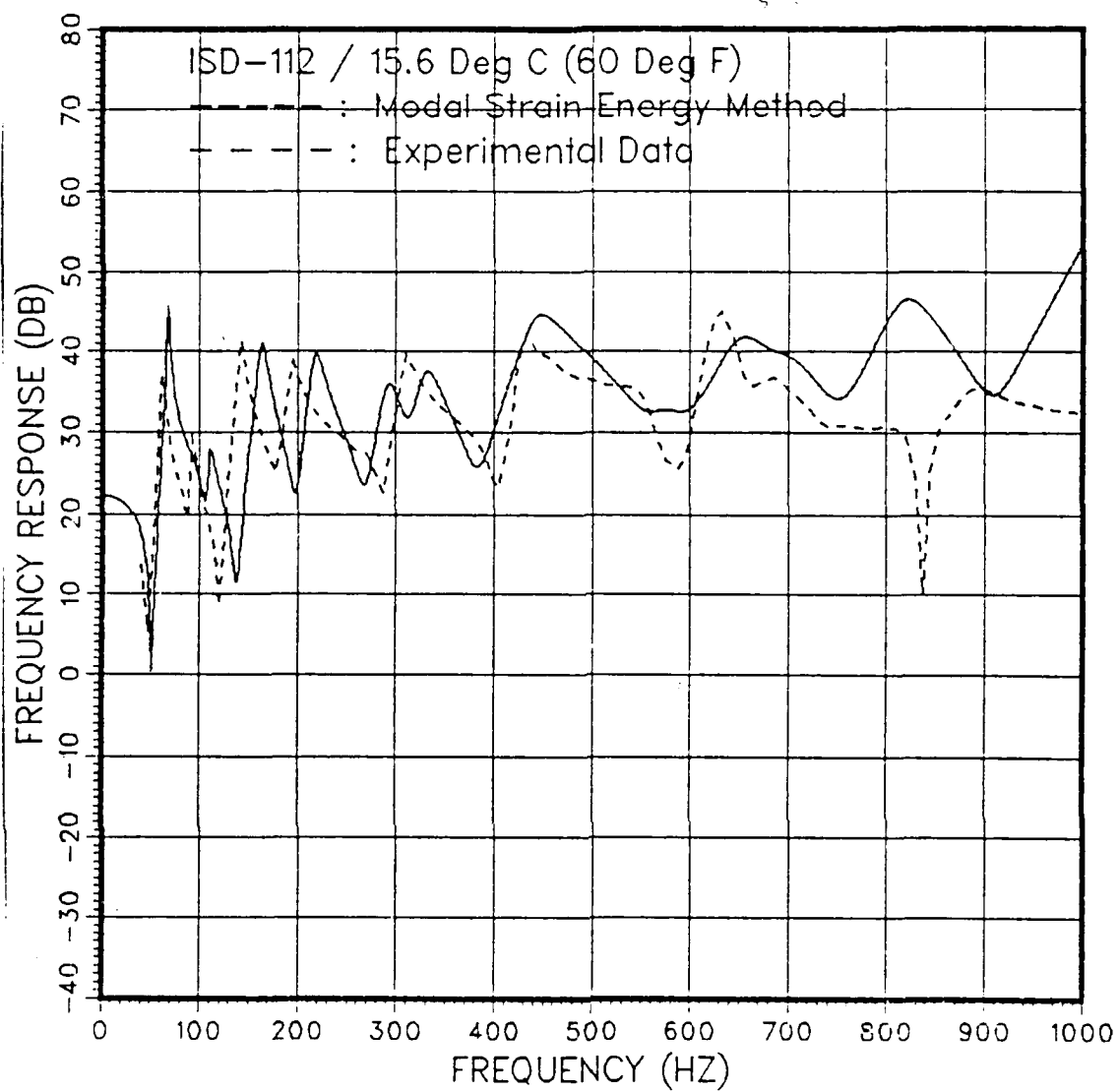


Figure 4.10. Comparison of Estimated and Measured Frequency Response for the Spot Welded Pocket Plate at 15.6 °C.

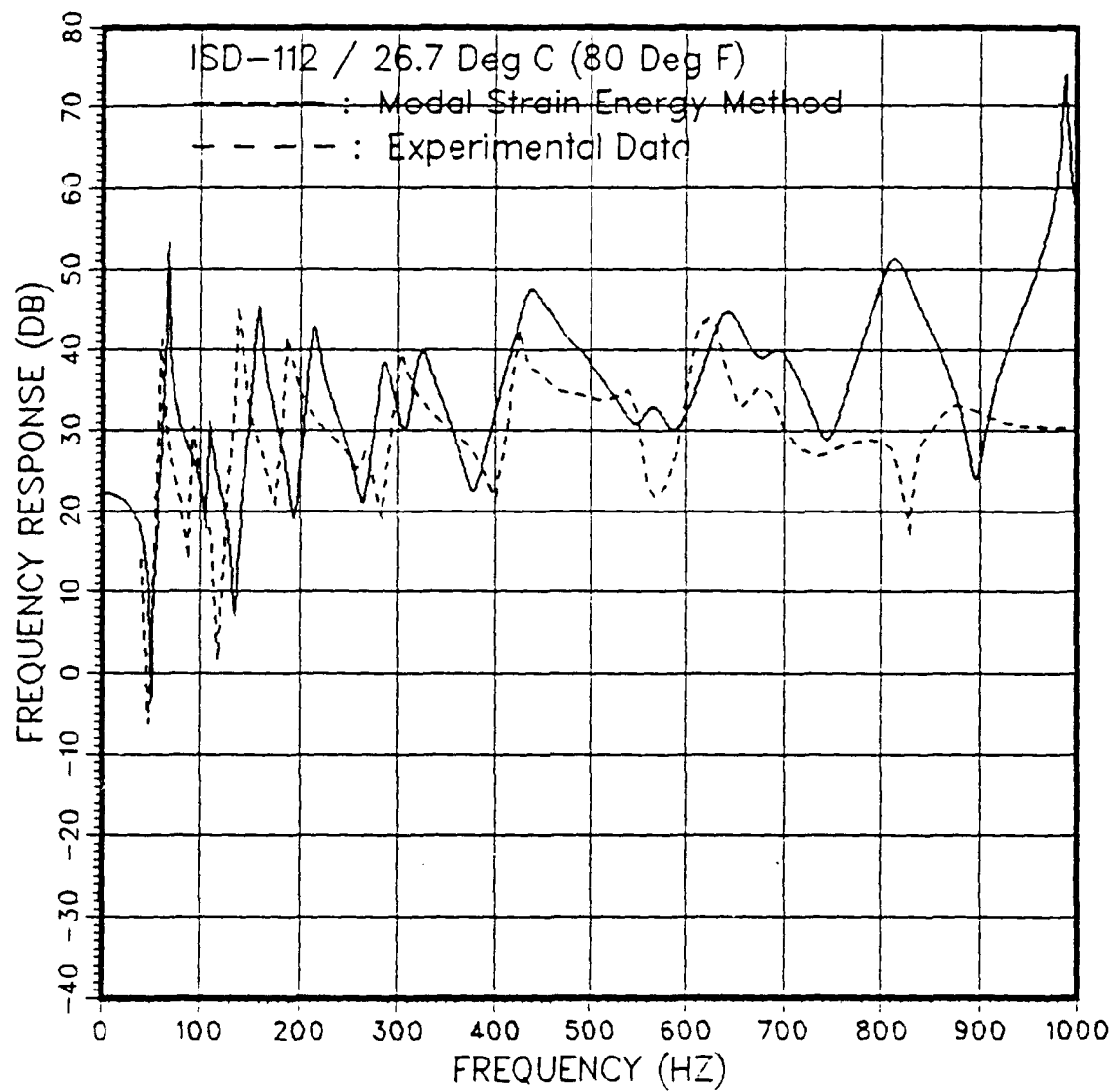


Figure 4.11. Comparison of Estimated and Measured Frequency Response for the Spot Welded Pocket Plate at 26.7 °C.

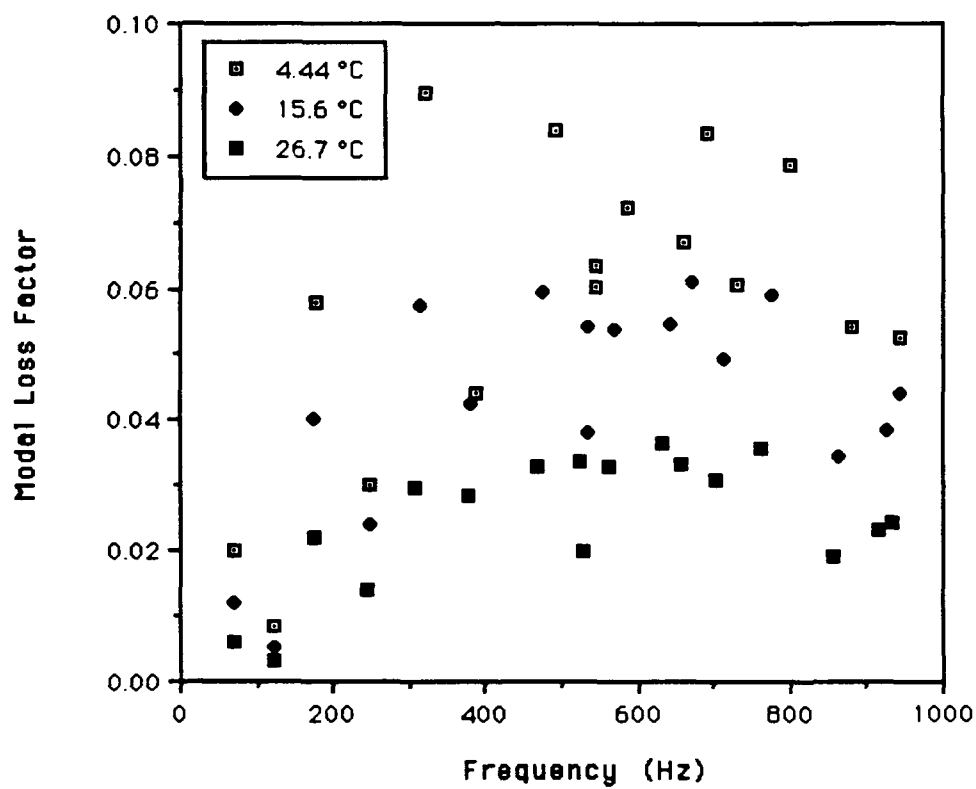


Figure 4.12 Estimated Modal Loss Factor for Line Welded Pocket Plate at 4.44/15.6/26.7 °C.

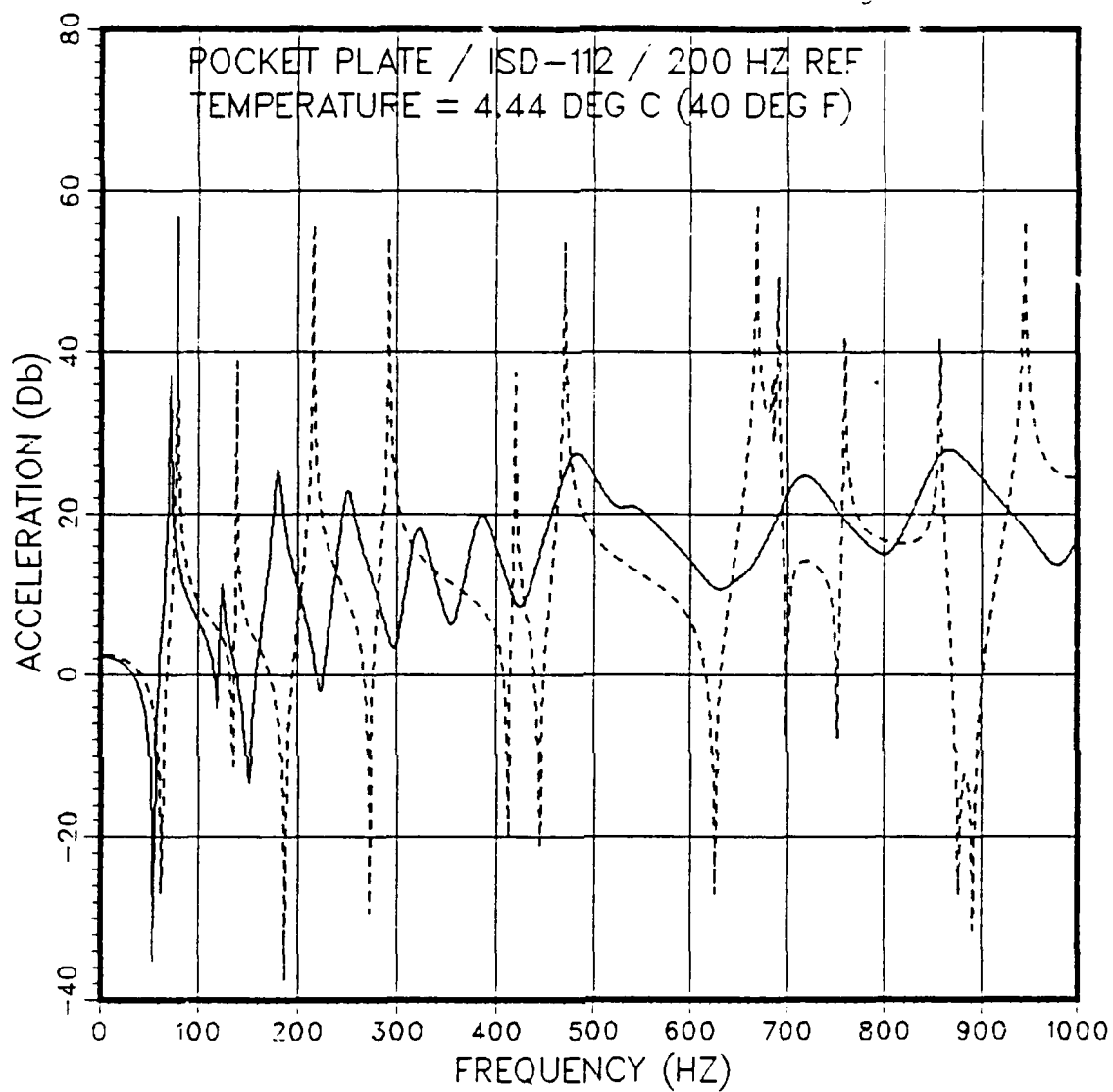


Figure 4.13. Calculated Modal Frequency Response of the Line Welded Pocket Plate at 4.44 °C.

[- - - - : reference plate , — : line welded pocket plate]

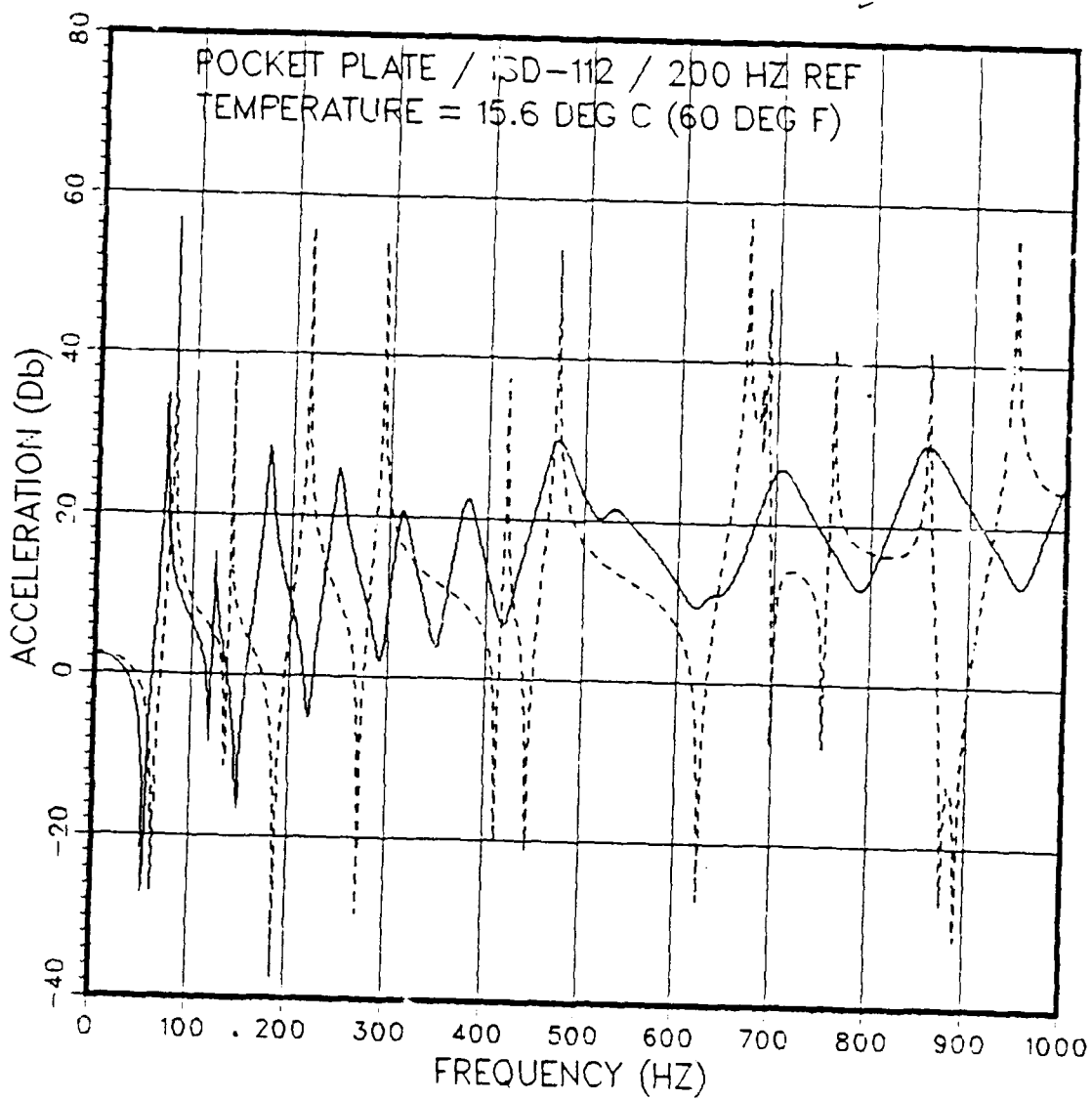


Figure 4.14. Calculated Modal Frequency Response of the Line Welded Pocket Plate at 15.6 °C.

[- - - - : reference plate , — : line welded pocket plate]

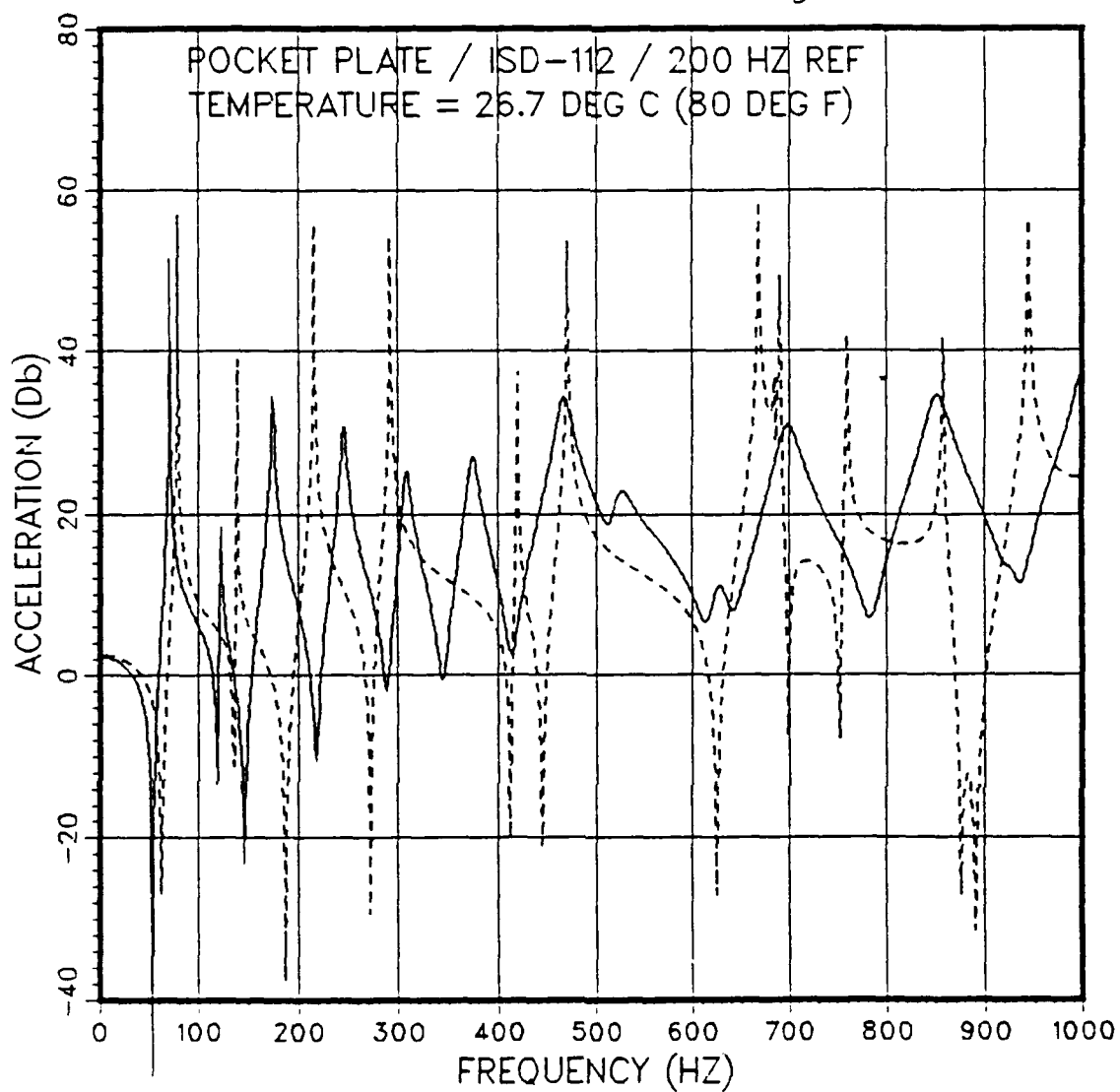


Figure 4.15. Calculated Modal Frequency Response of the Line Welded Pocket Plate at 26.7 °C.

[- - - - : reference plate , — : line welded pocket plate]

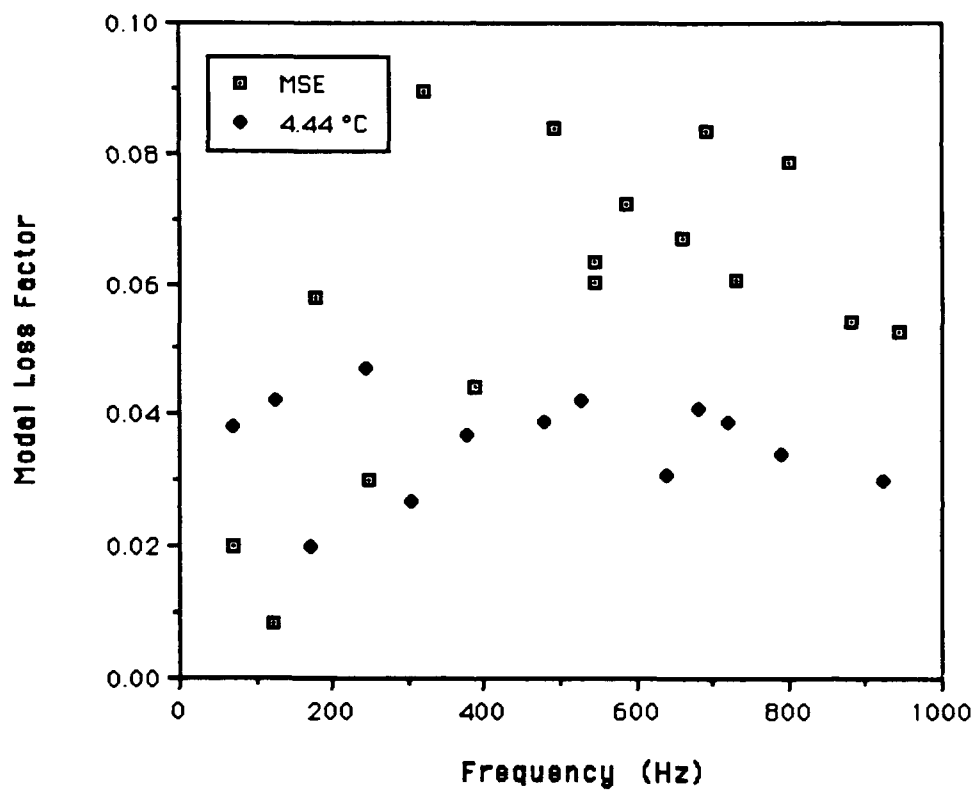


Figure 4.16. Comparison of Estimated and Measured Modal Loss Factors for Line Welded Pocket Plate at 4.44 °C.

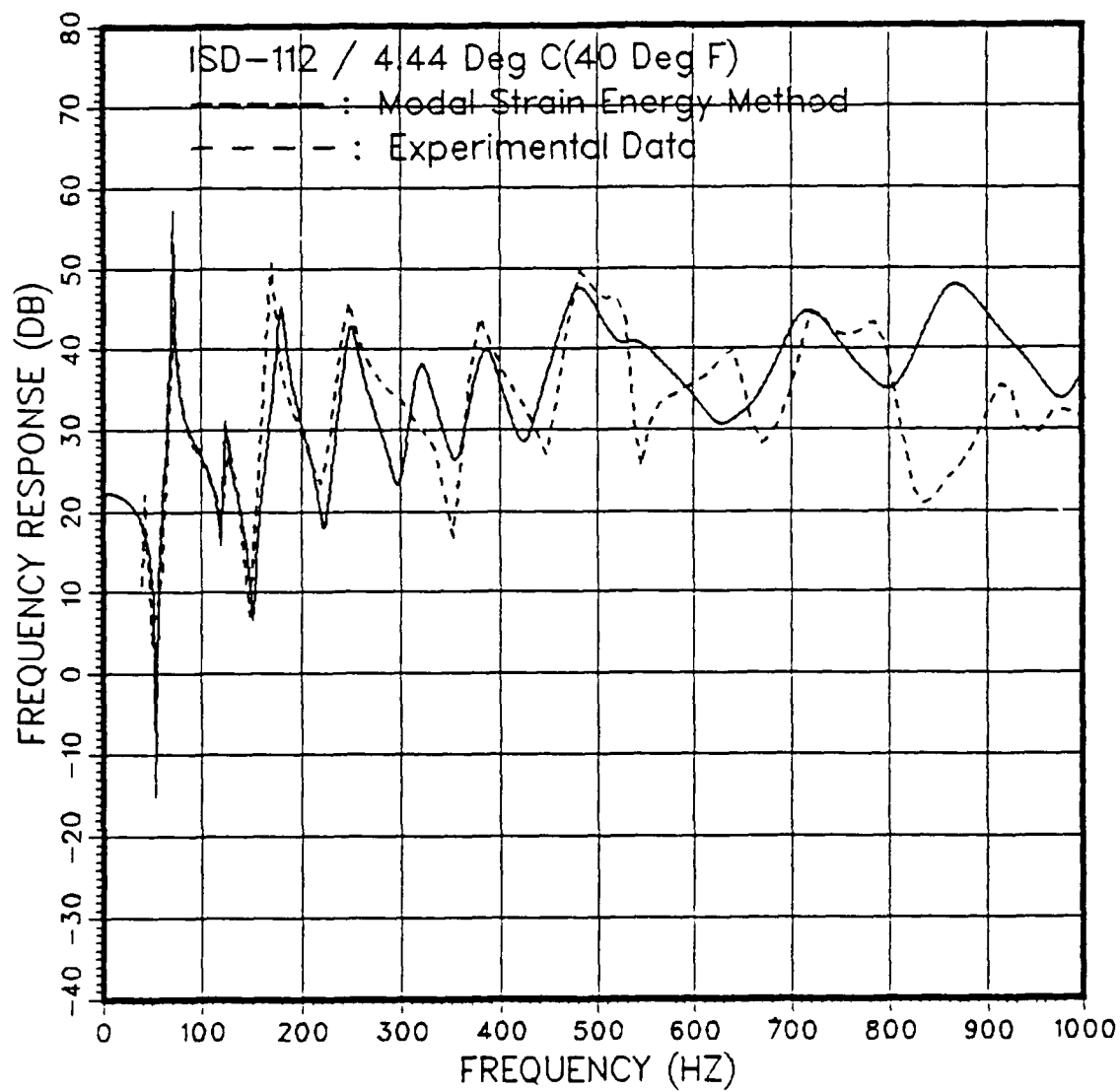


Figure 4.17. Comparison of Estimated and Measured Frequency Response for the Line Welded Pocket Plate at 4.44 °C.

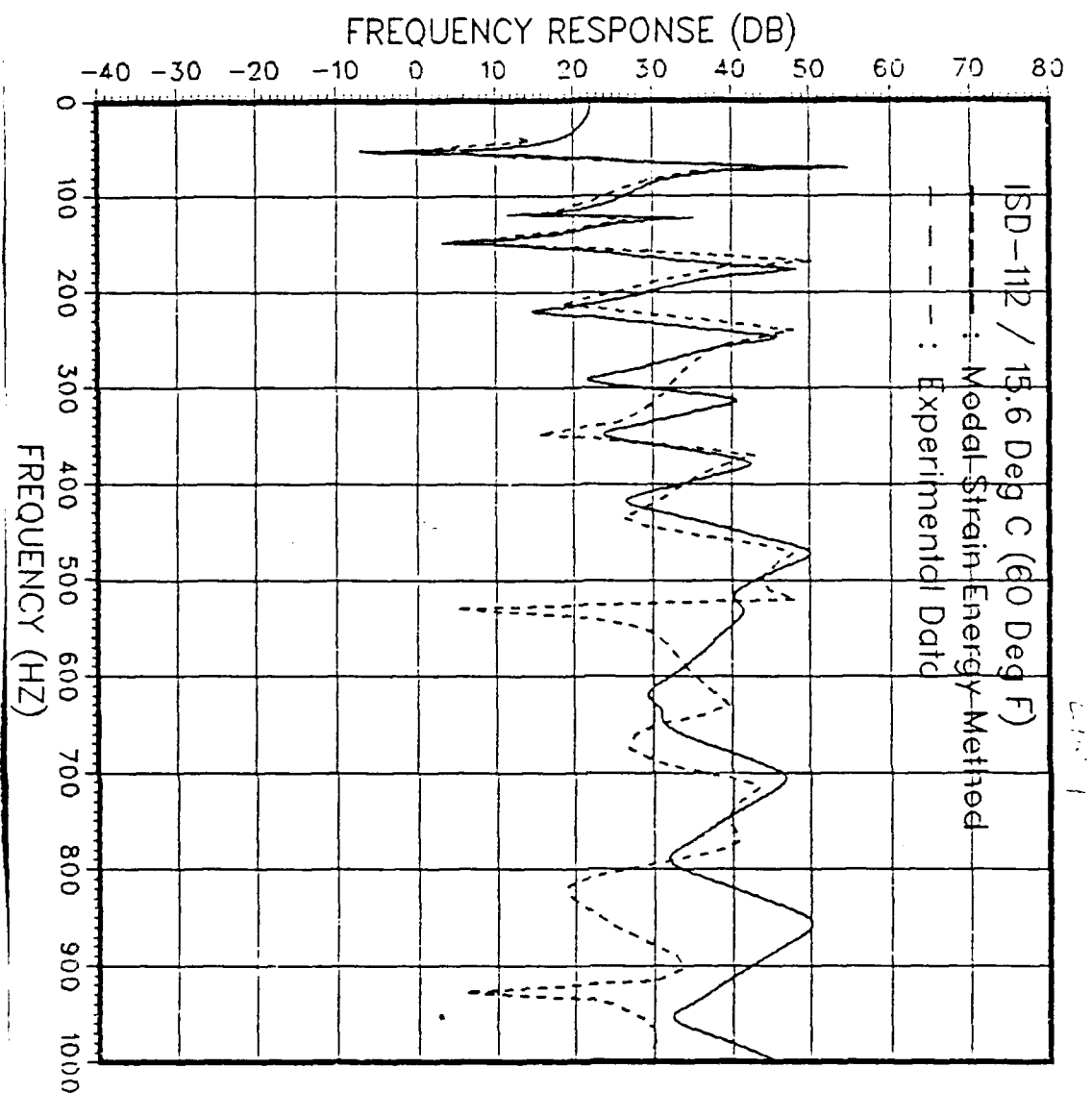


Figure 4.18. Comparison of Estimated and Measured Frequency Response for the Line Welded Pocket Plate at 15.6 °C.

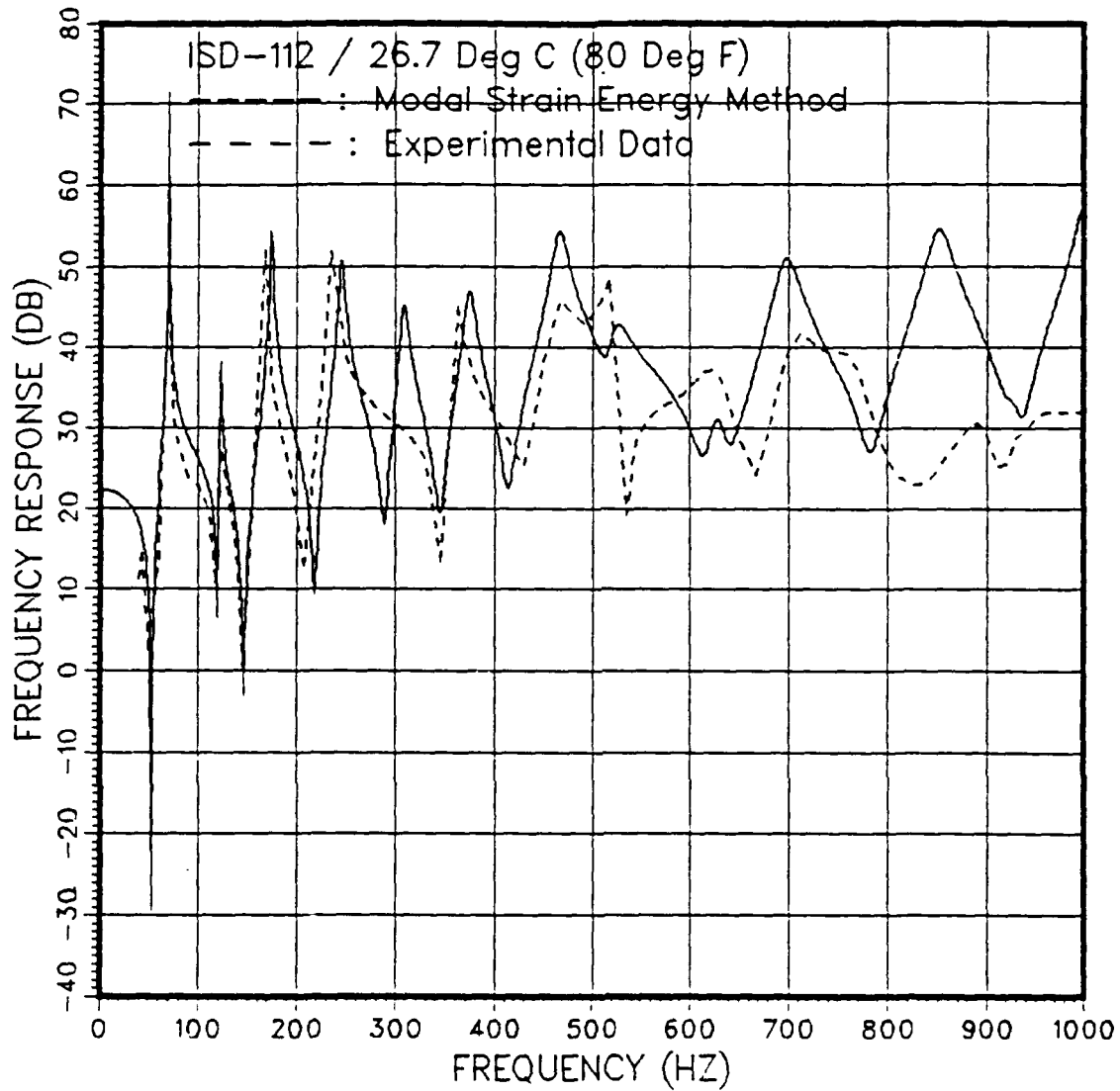


Figure 4.19. Comparison of Estimated and Measured Frequency Response for the Line Welded Pocket Plate at 26.7 °C.

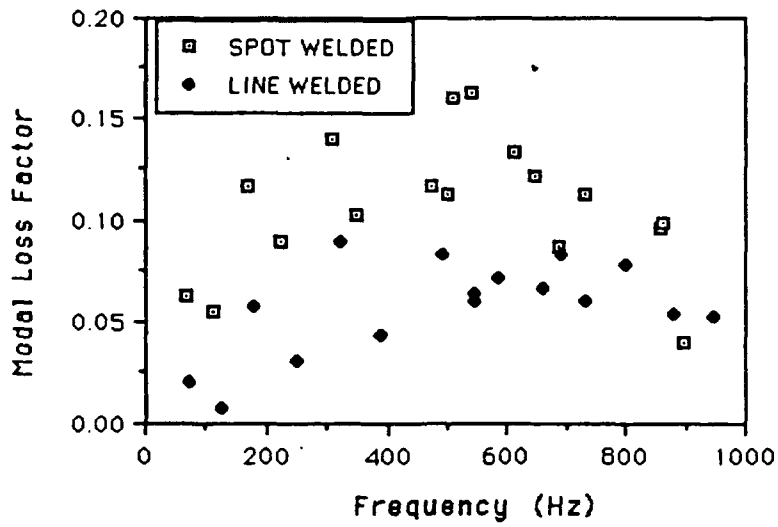


Figure 4.20. Comparison of Estimated Modal Loss Factor for Spot and Line Welded Pocket Plate at 4.44 °C.

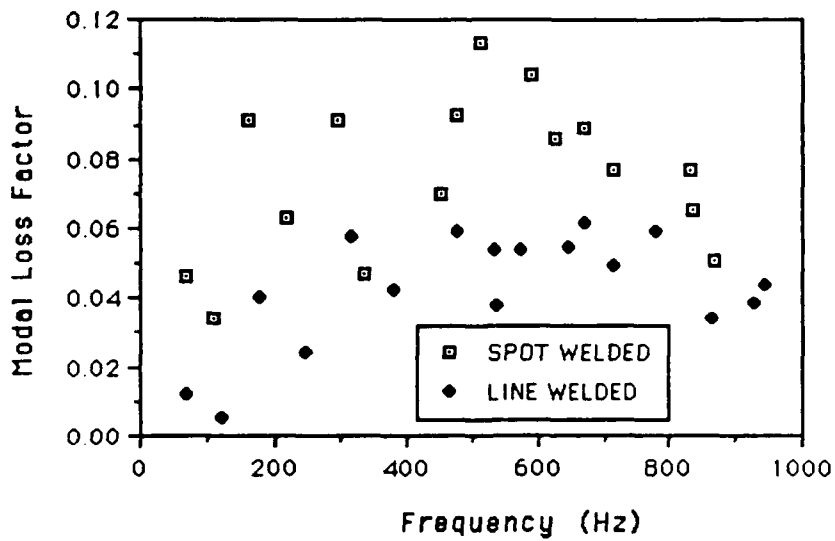


Figure 4.21. Comparison of Estimated Modal Loss Factor for Spot and Line Welded Pocket Plate at 15.6 °C.

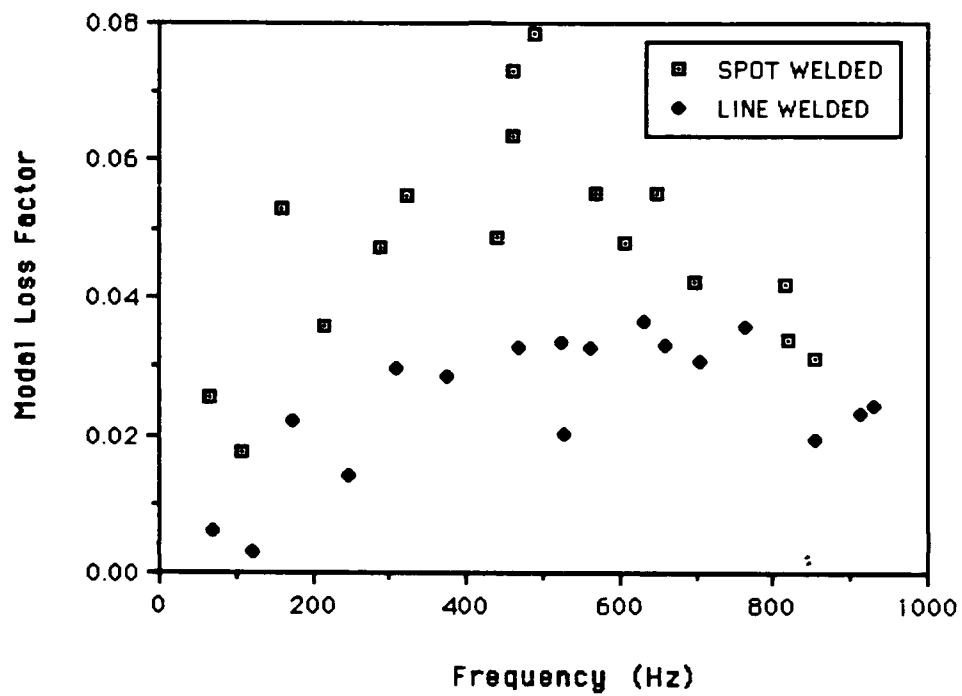


Figure 4.22. Comparison of Estimated Modal Loss Factor for Spot and Line Welded Pocket Plate at 26.7 °C.

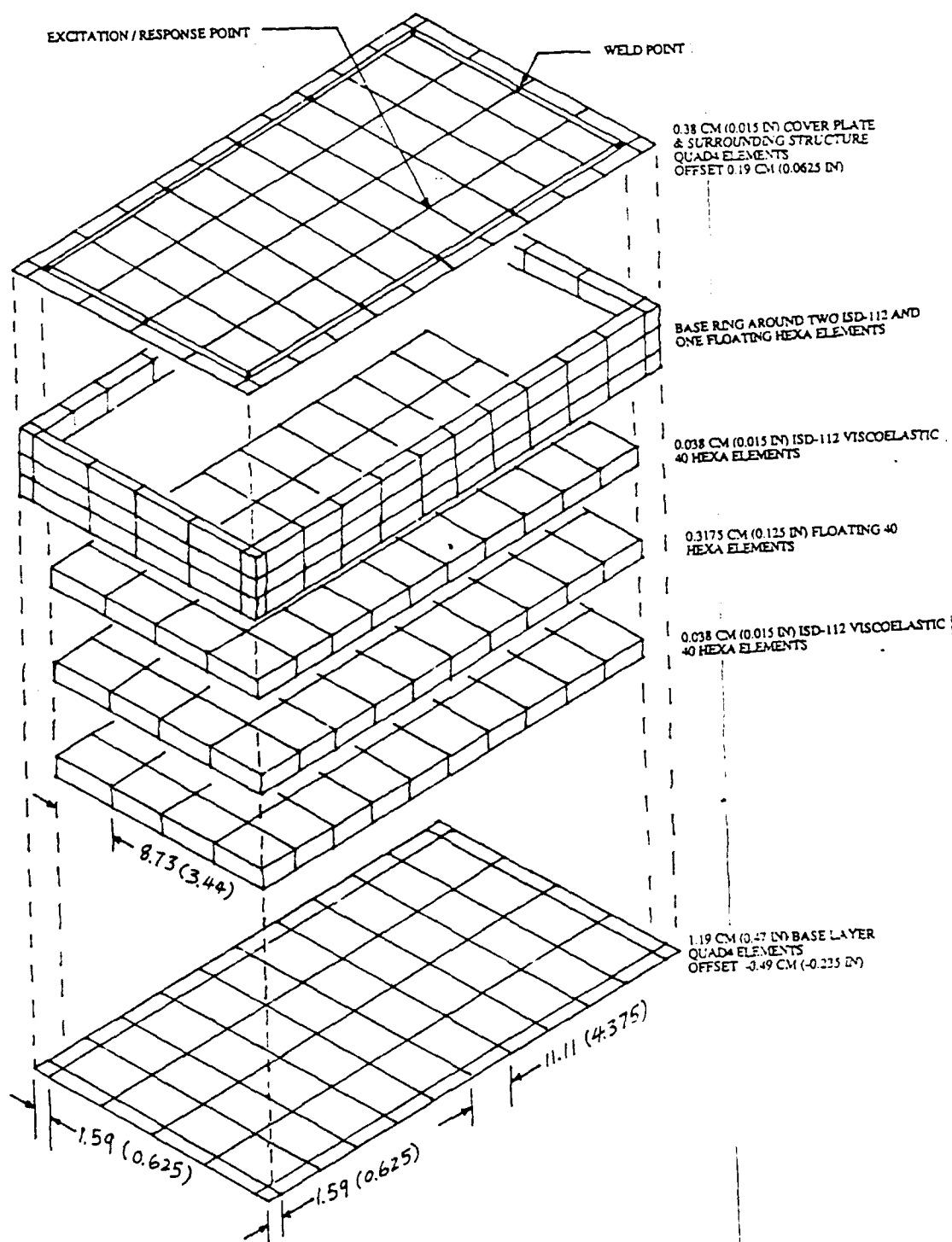


Figure 4.23. Finite Element Representation of the Floating Element Plate Configuration.

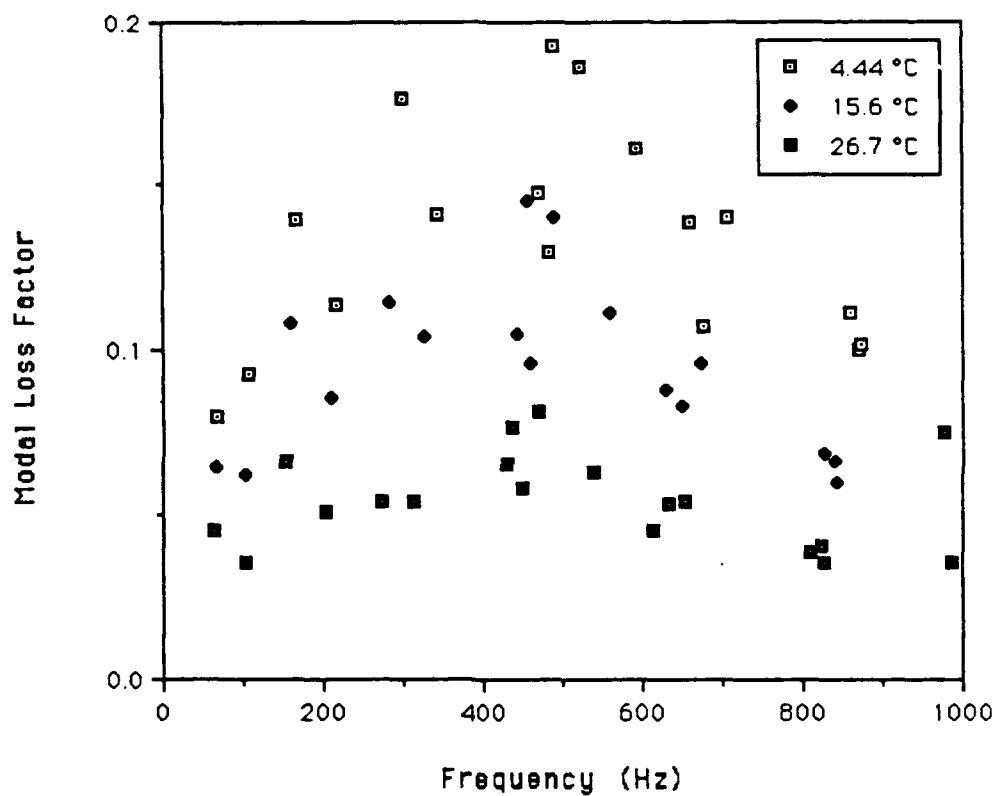


Figure 4.24. Estimated Modal Loss Factor for Spot Welded Floating Element Plate at 4.44/15.6/26.7 °C.

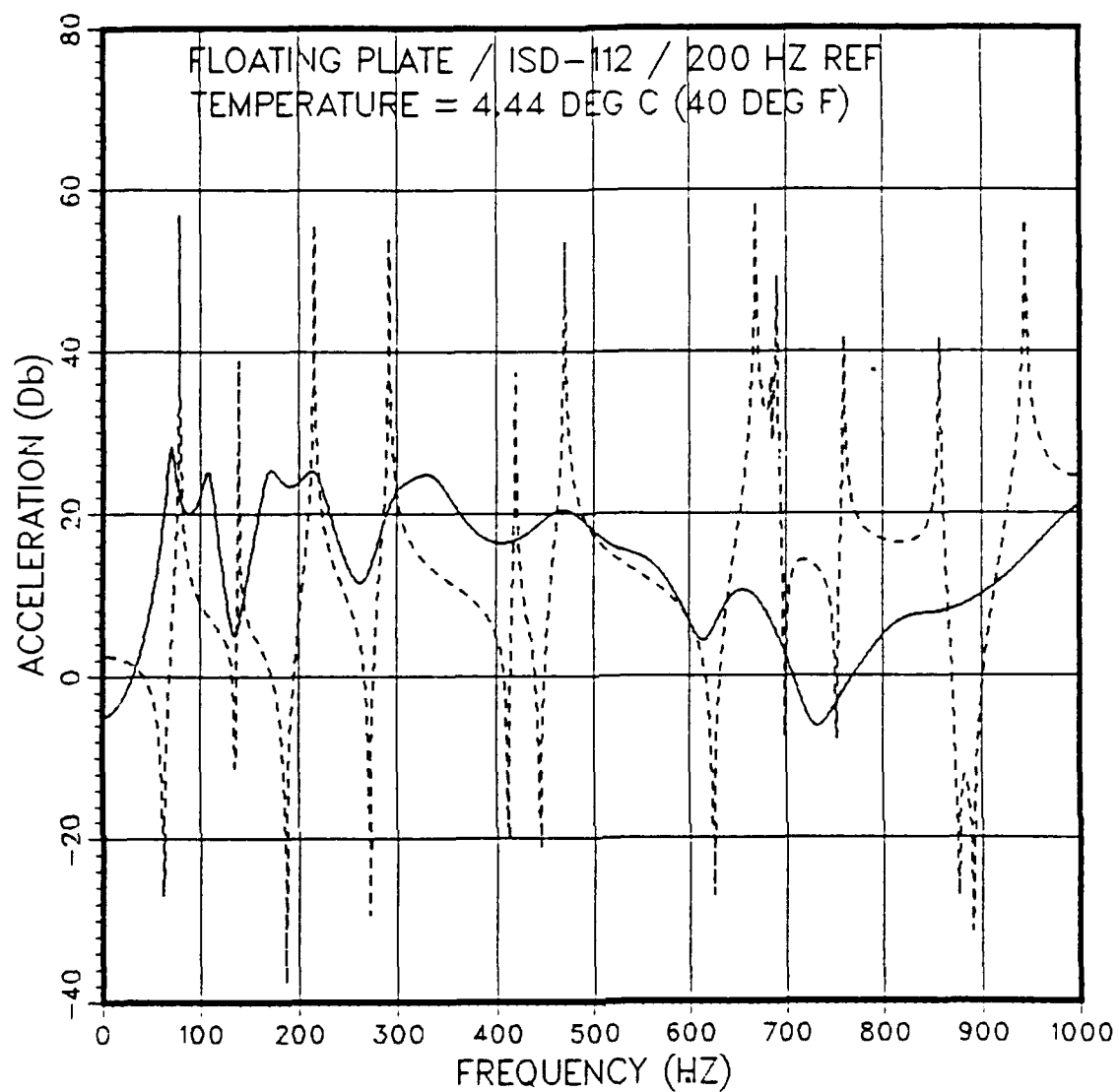


Figure 4.25. Calculated Modal Frequency Response of the Spot Welded Floating Element Configuration Using NASTRAN.

[- - - - : reference plate , — : spot welded floating element]

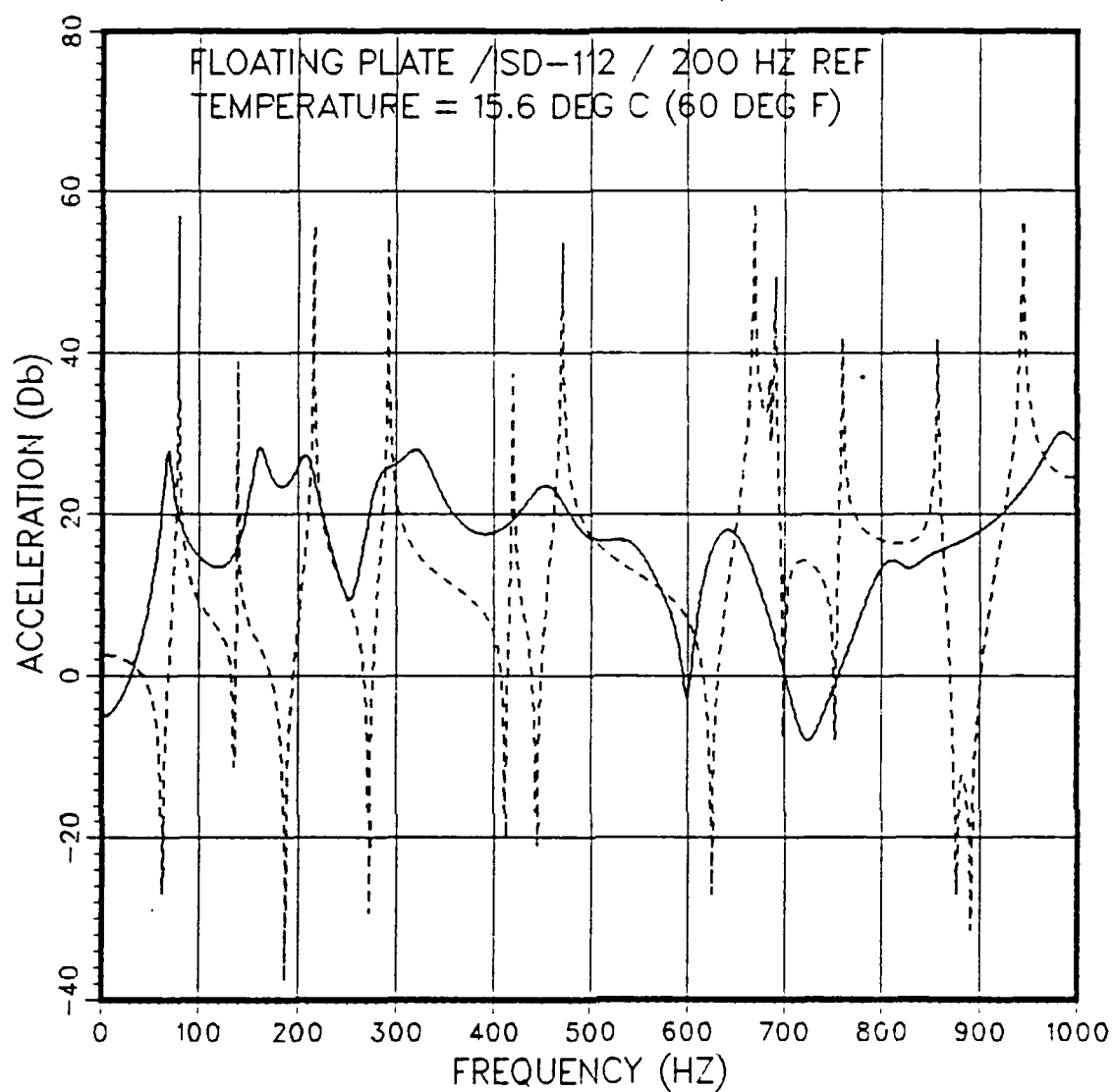


Figure 4.26. Calculated Modal Frequency Response of the Spot Welded Floating Element Configuration Using NASTRAN.

[- - - - : reference plate , — : spot welded floating element]

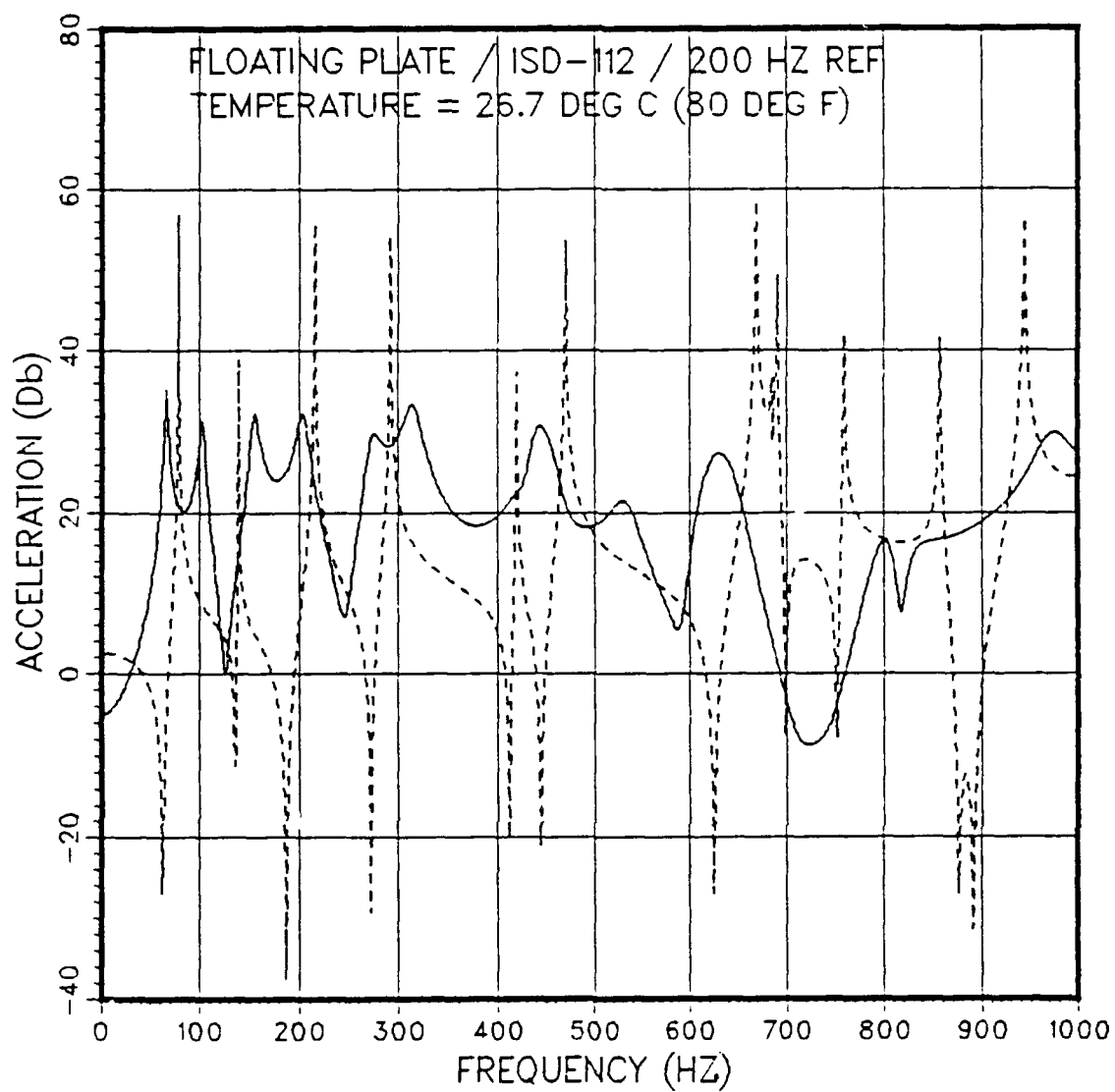


Figure 4.27. Calculated Modal Frequency Response of the Spot Welded Floating Element Configuration Using NASTRAN.

[- - - - : reference plate , — : spot welded floating element]

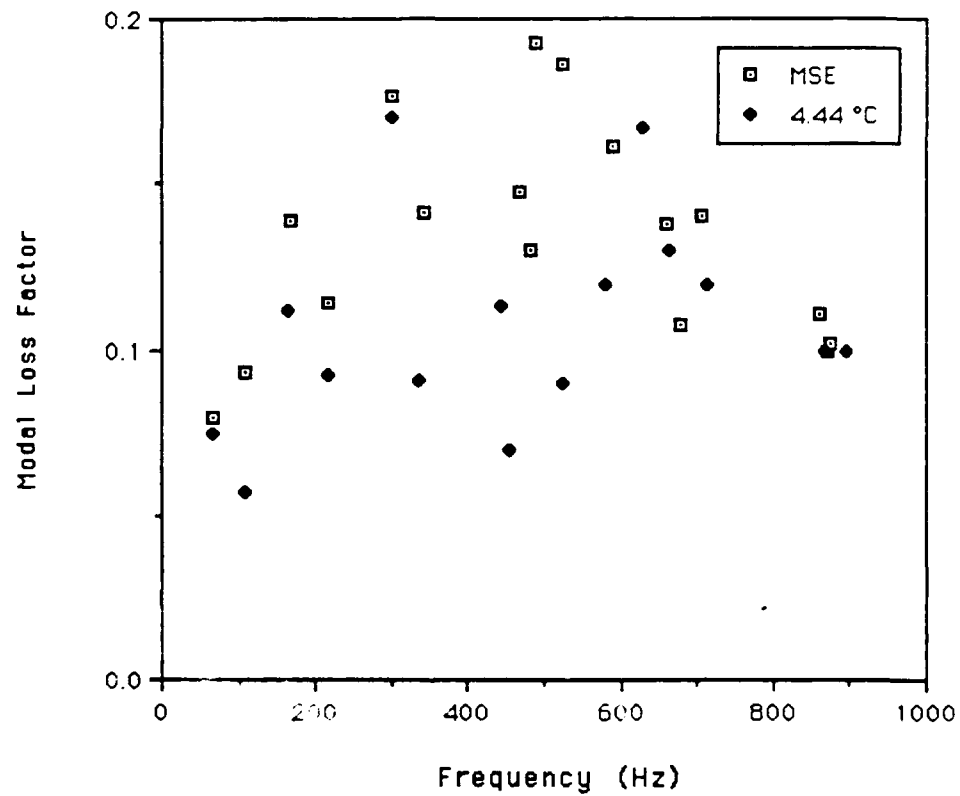


Figure 4.28. Comparison of Estimated and Measured Modal Loss Factors for Spot Welded Floating Element Configuration.

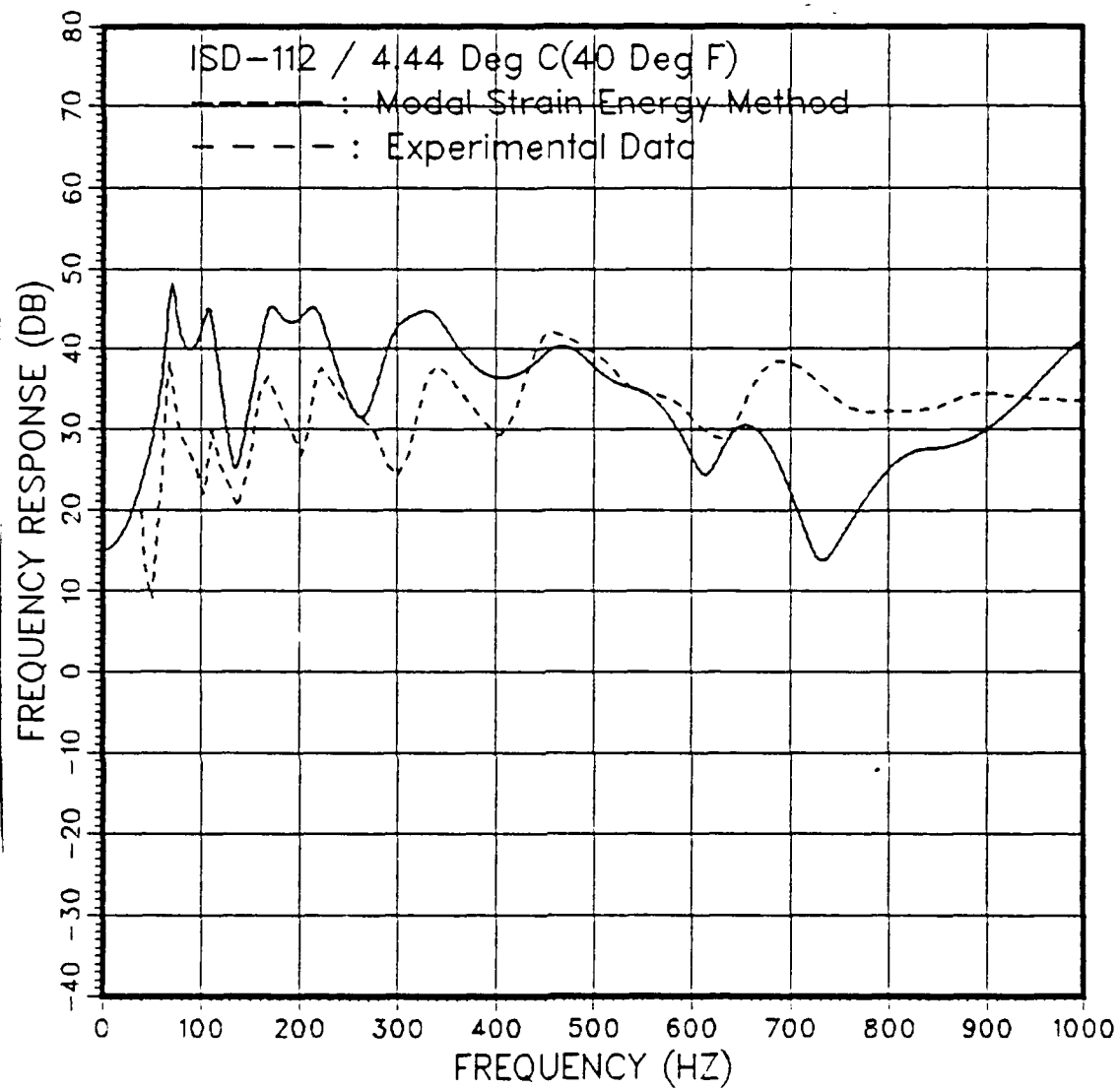


Figure 4.29. Comparison of Estimated and Measured Frequency Response for the Spot Welded Floating Element Configuration.

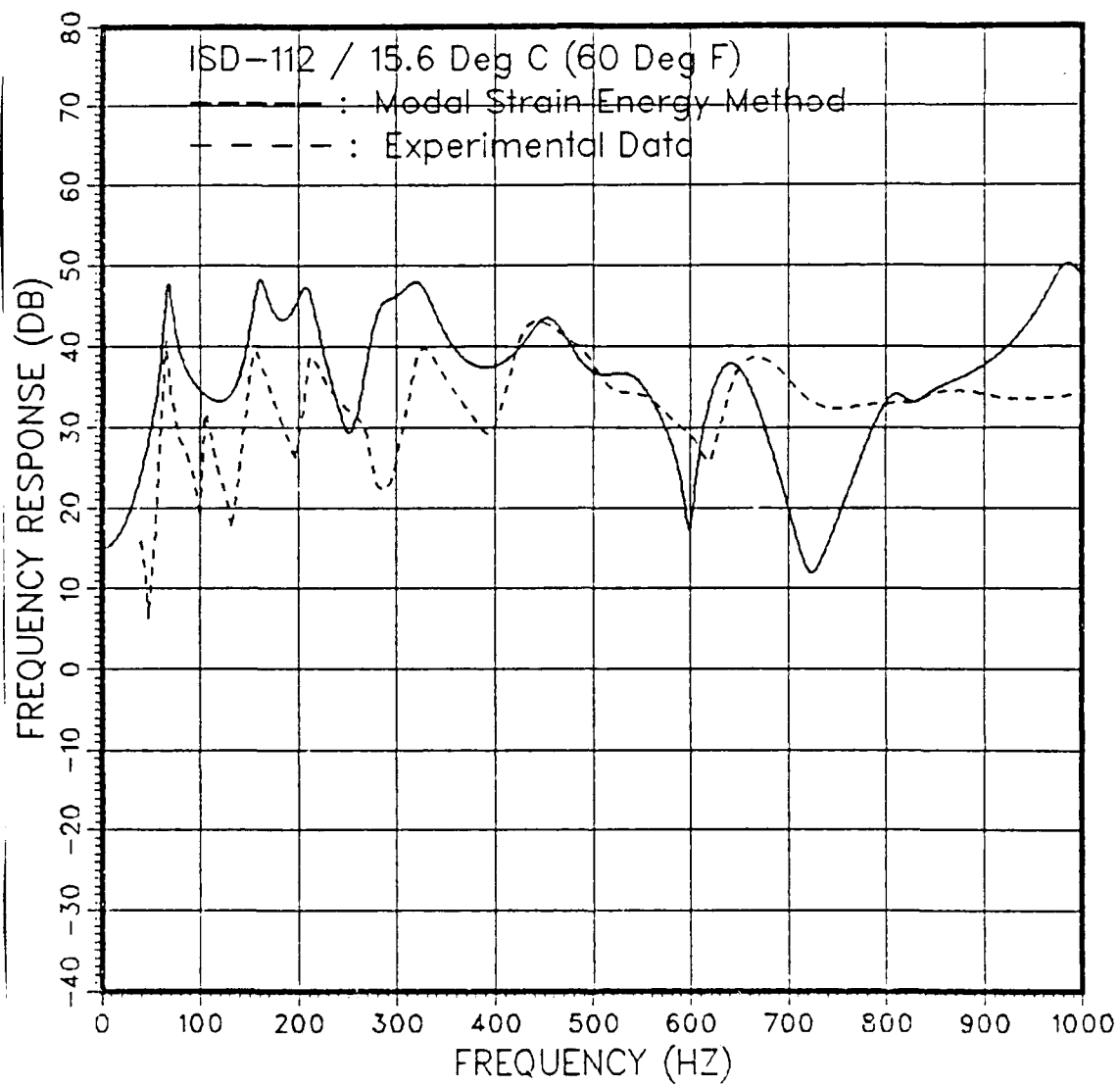


Figure 4.30. Comparison of Estimated and Measured Frequency Response for the Spot Welded Floating Element Configuration.

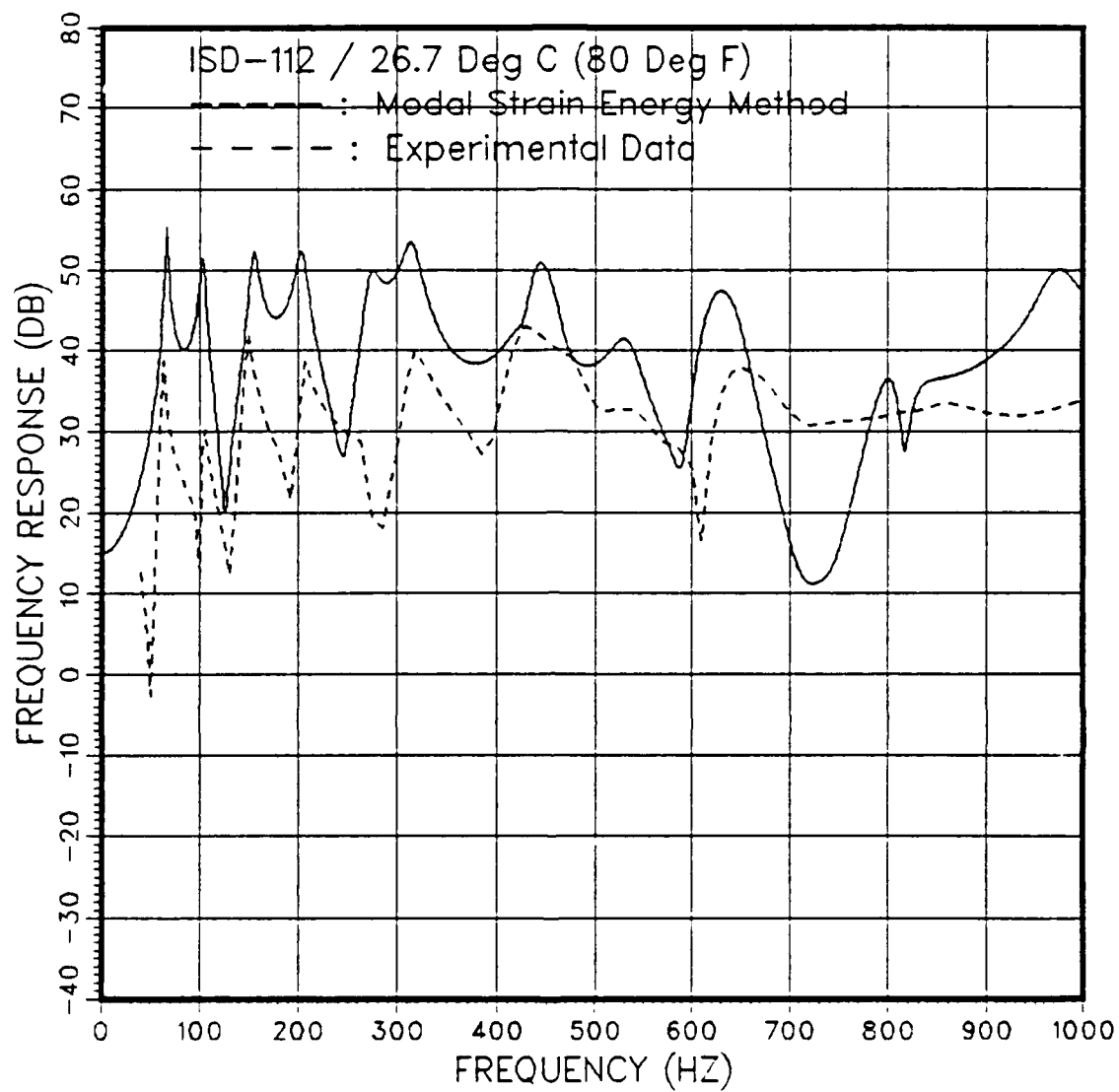


Figure 4.31. Comparison of Estimated and Measured Frequency Response for the Spot Welded Floating Element Configuration.

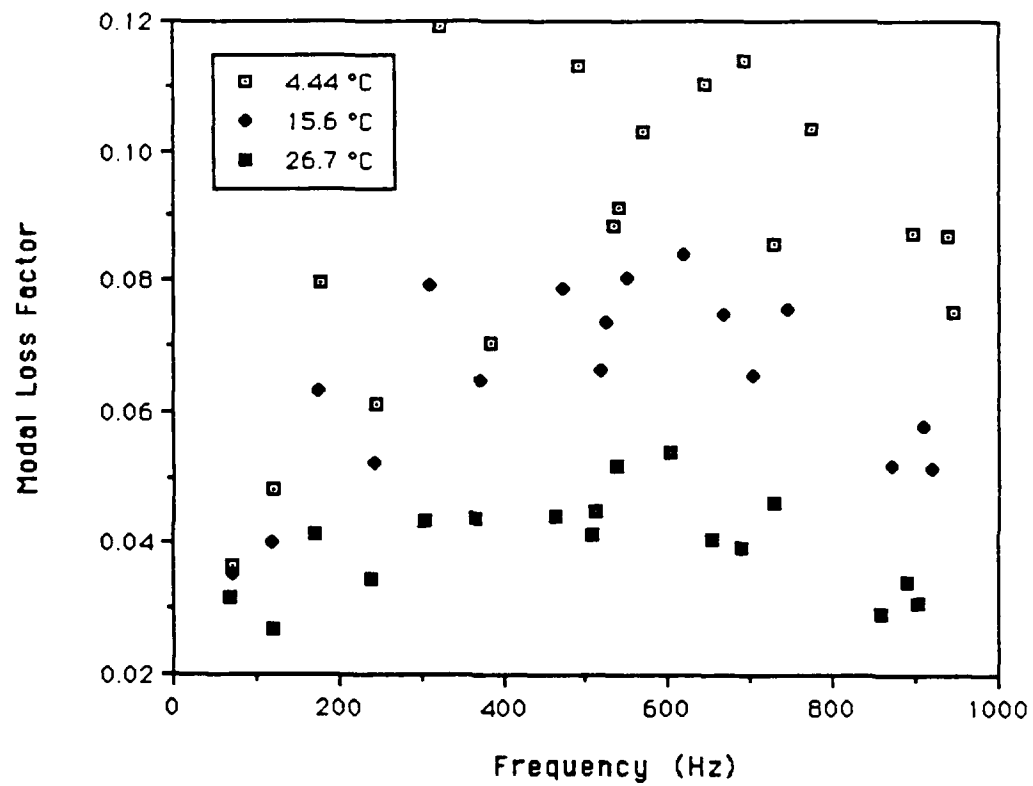


Figure 4.32. Modal Loss Factor for Line Welded Floating Element at 4.44/15.6/26.7 °C.

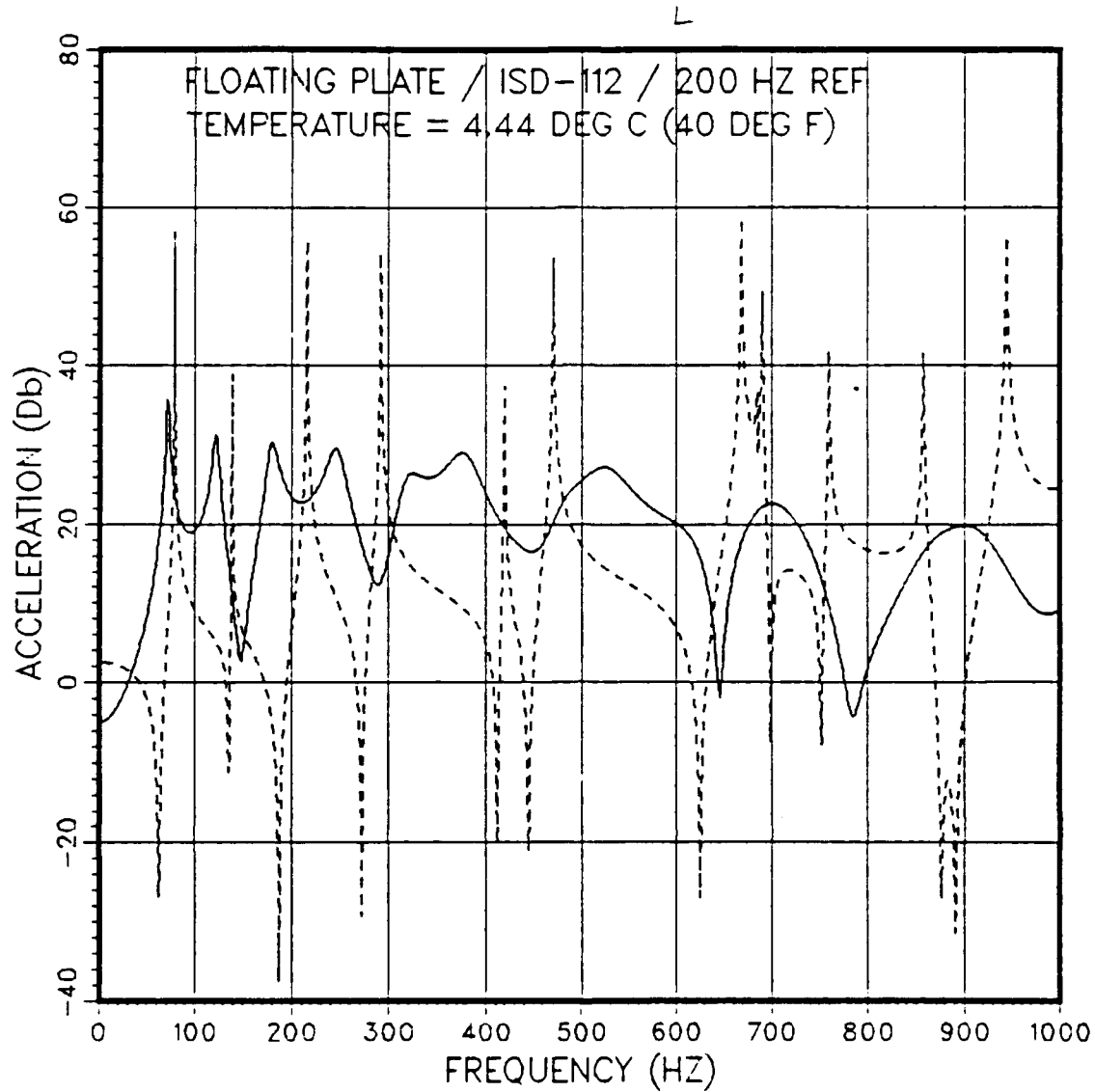


Figure 4.33. Calculated Modal Frequency Response of the Line Welded Floating Element Configuration Using NASTRAN.

[- - - - : reference plate , — : line welded pocket plate]

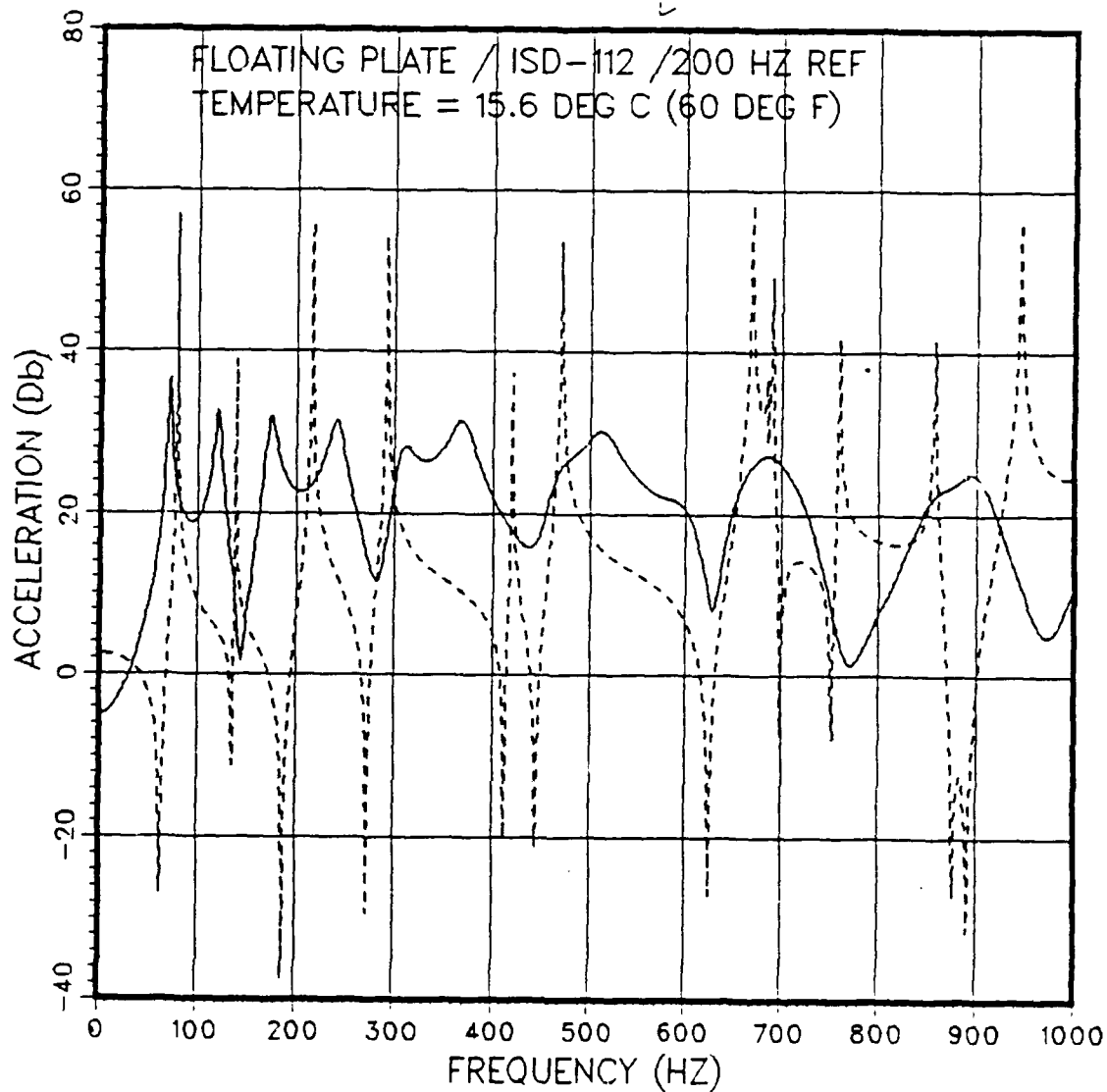


Figure 4.34. Calculated Modal Frequency Response of the Line Welded Floating Element Configuration Using NASTRAN.

[- - - - : reference plate , — : line welded pocket plate]

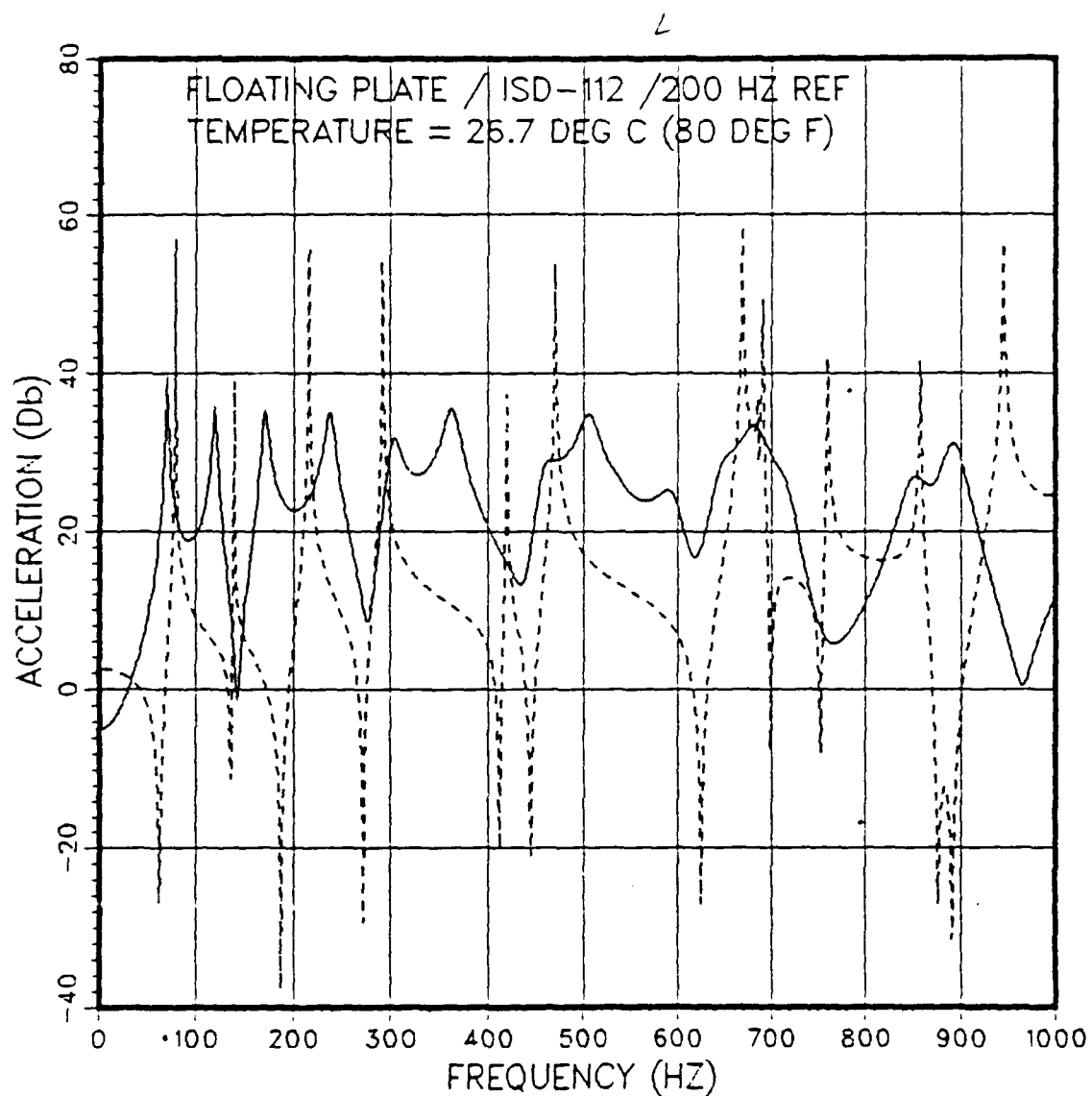


Figure 4.35. Calculated Modal Frequency Response of the Line Welded Floating Element Configuration Using NASTRAN.

[- - - - : reference plate , — : line welded pocket plate]

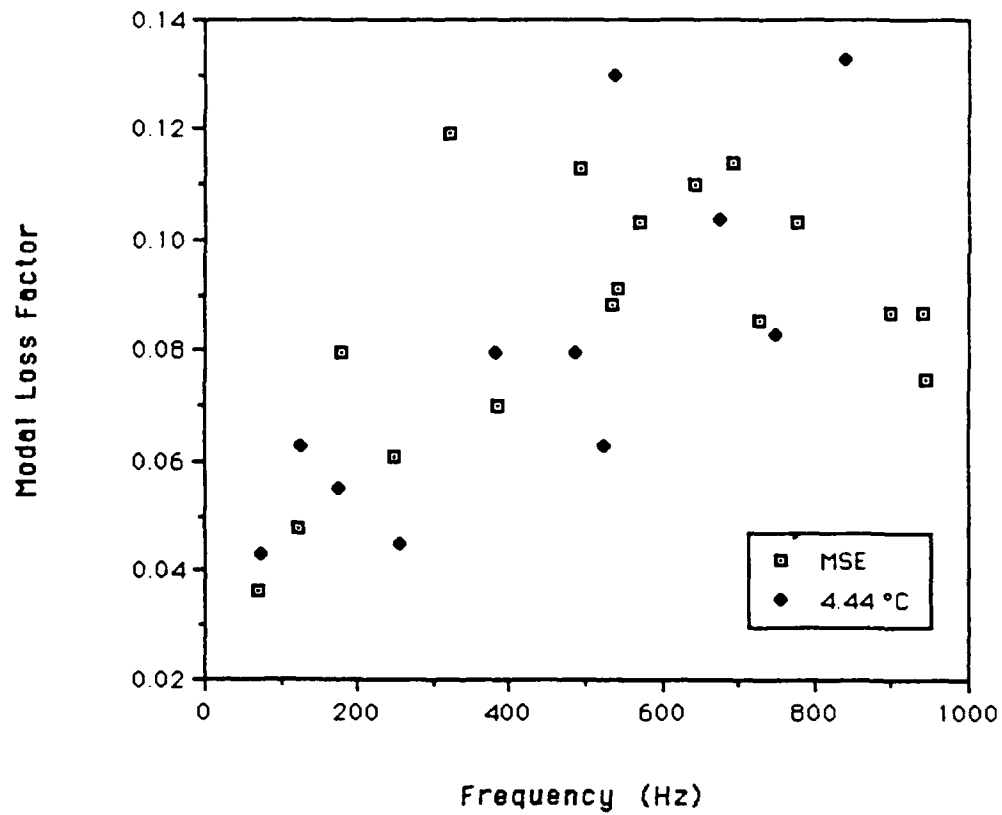


Figure 4.36. Comparison of Estimated and Measured Modal Loss Factors for Line Welded Floating Element Configuration.

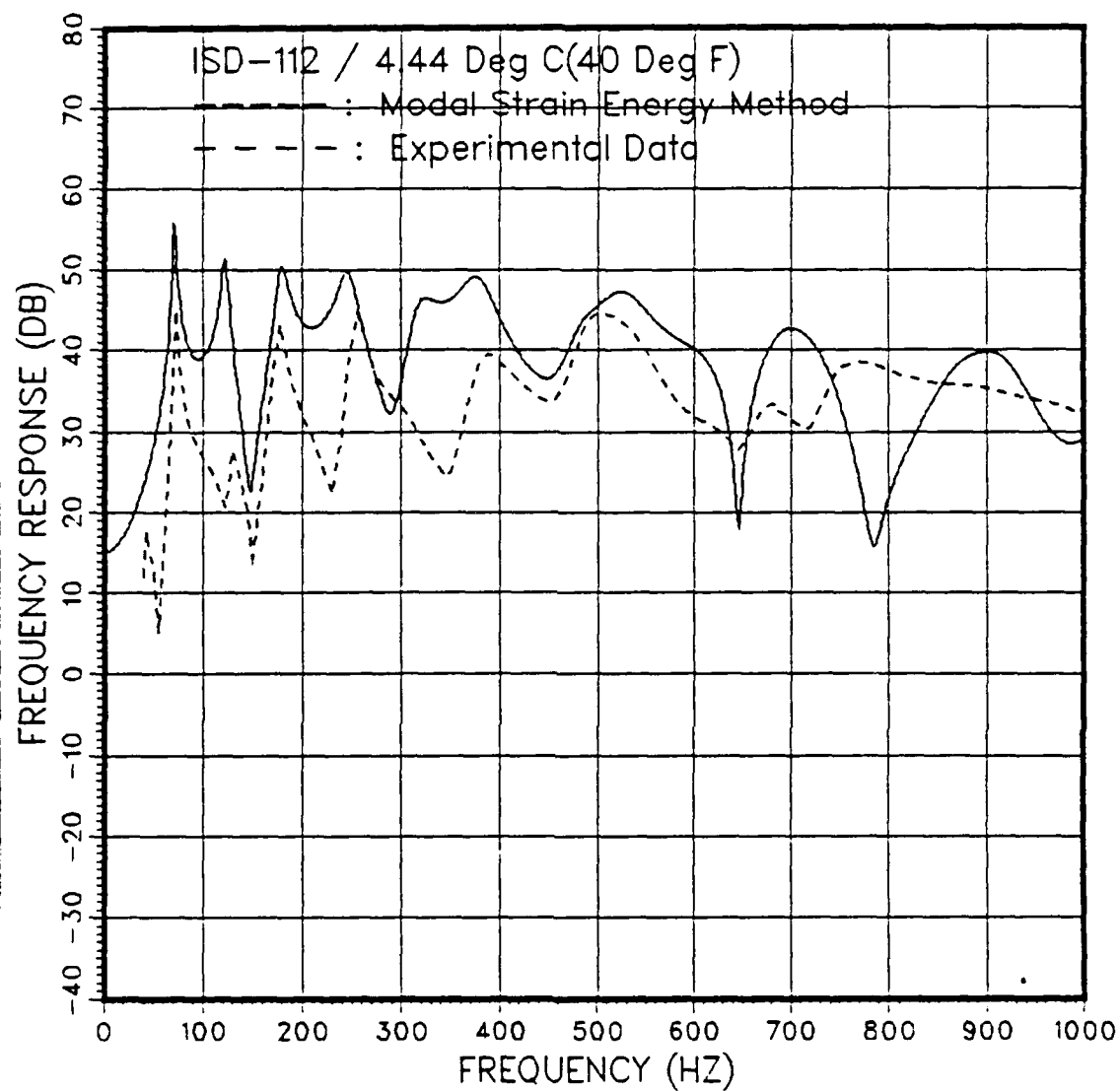


Figure 4.37. Comparison of Estimated and Measured Frequency Response for the Line Welded Floating Element Configuration.

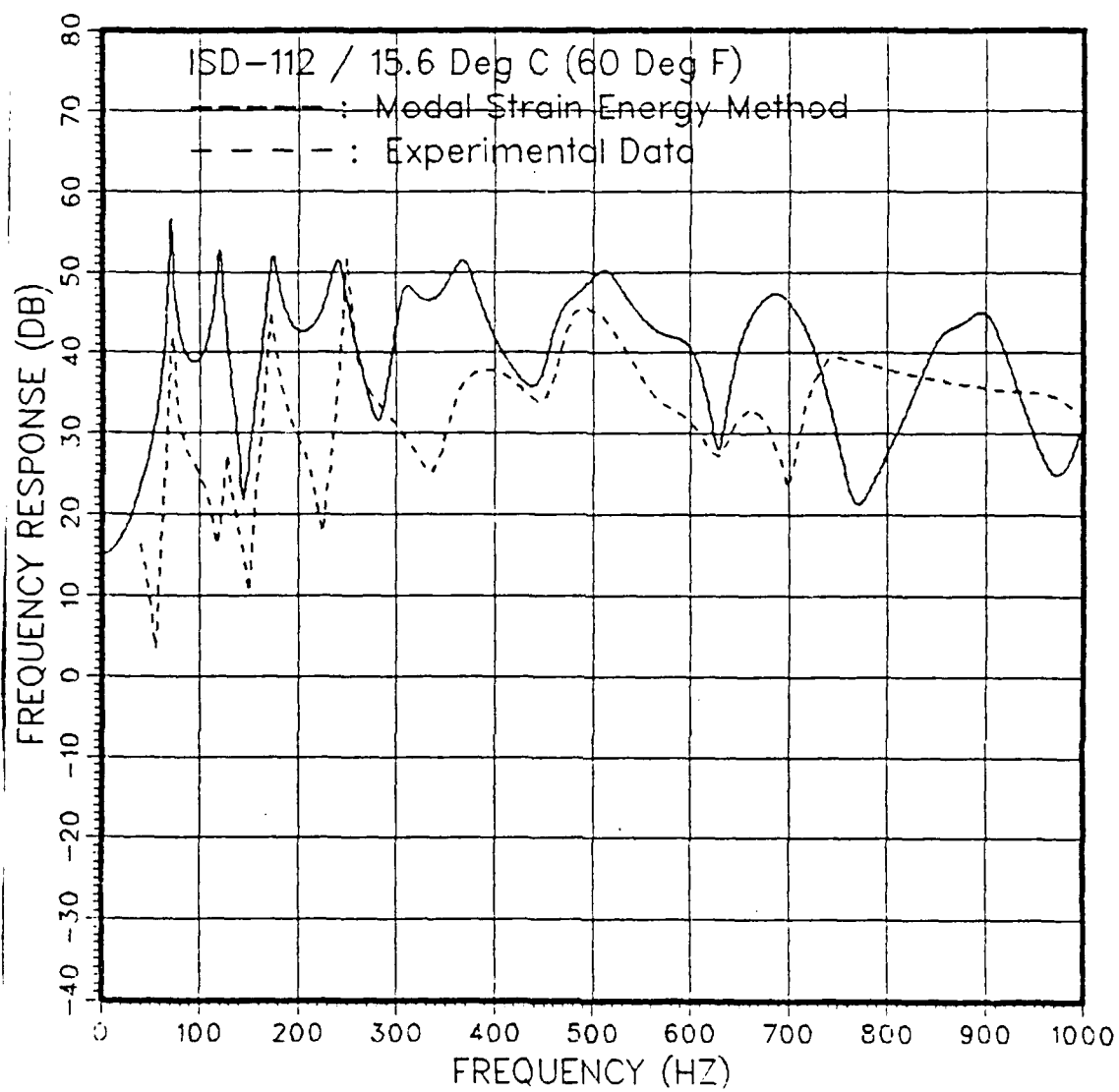


Figure 4.38. Comparison of Estimated and Measured Frequency Response for the Line Welded Floating Element Configuration.

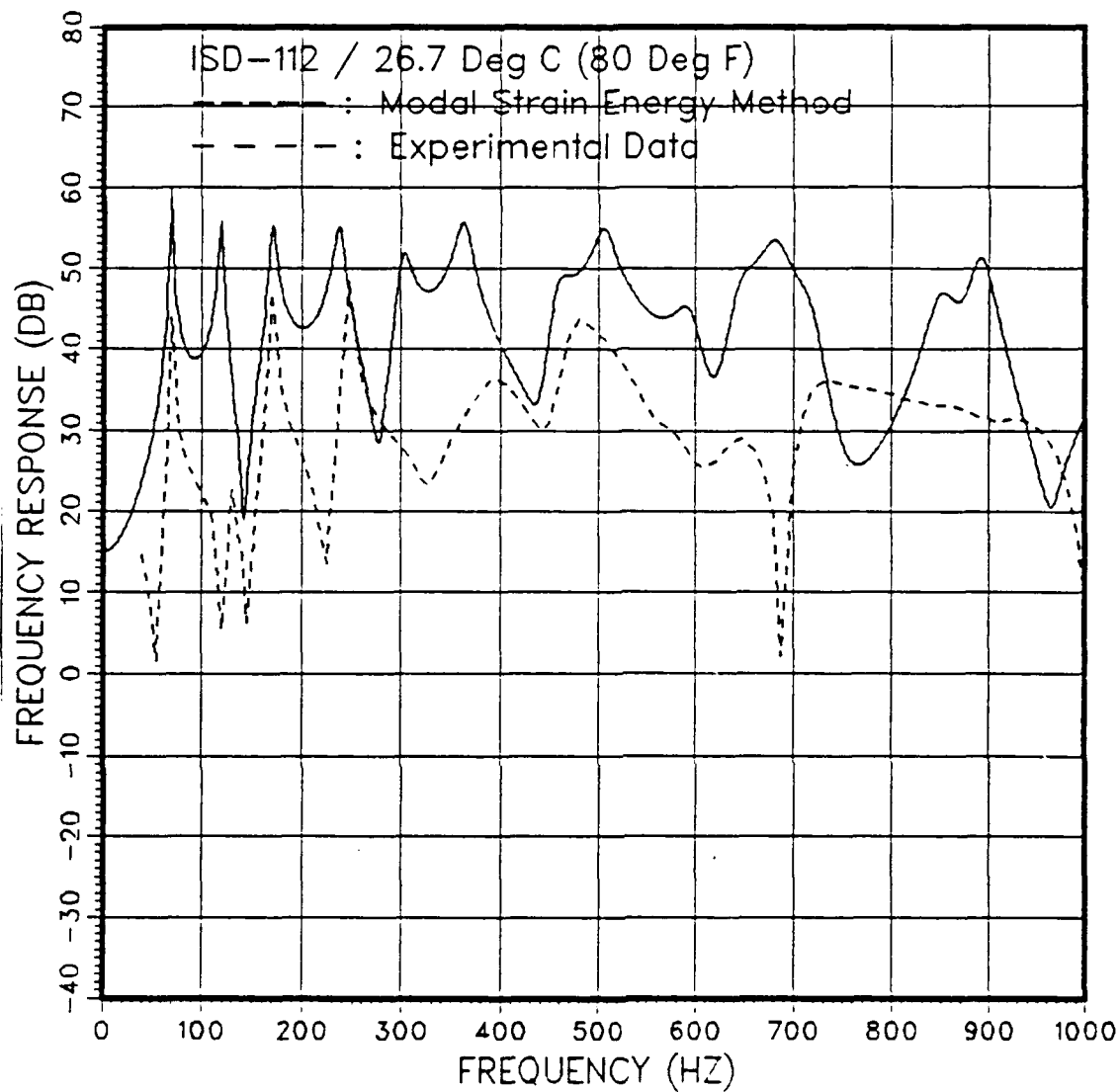


Figure 4.39. Comparison of Estimated and Measured Frequency Response for the Line Welded Floating Element Configuration.

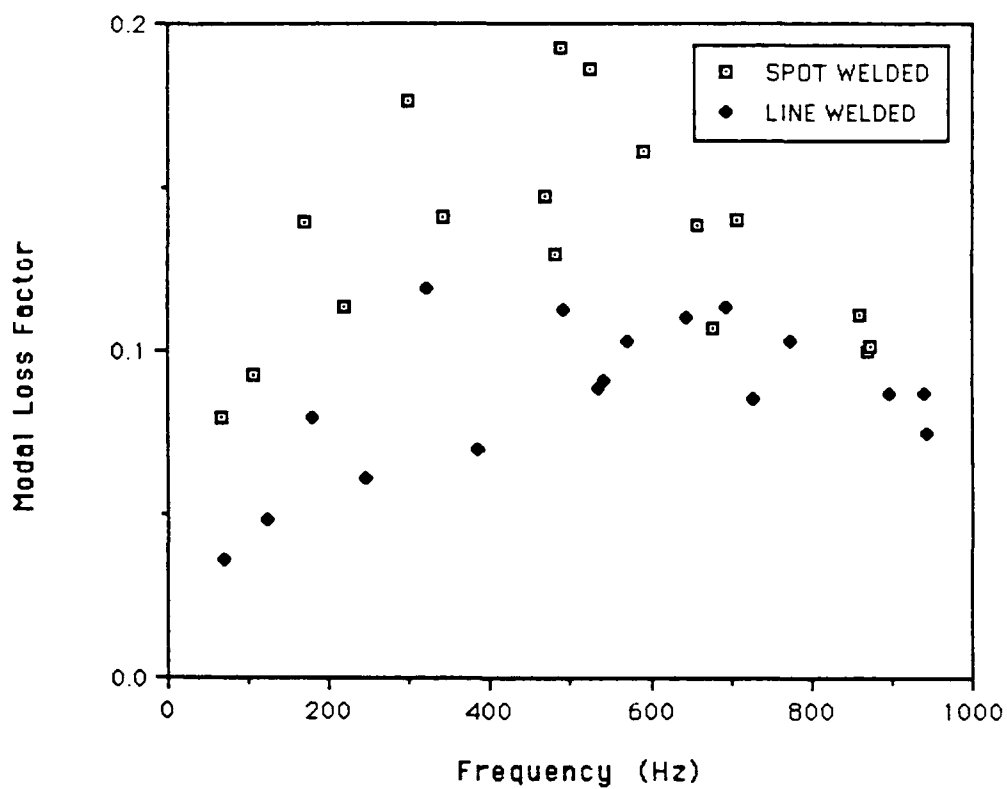


Figure 4.40. Comparison of Modal Loss Factor for Spot and Line Welded Floating Element at 4.44 °C.

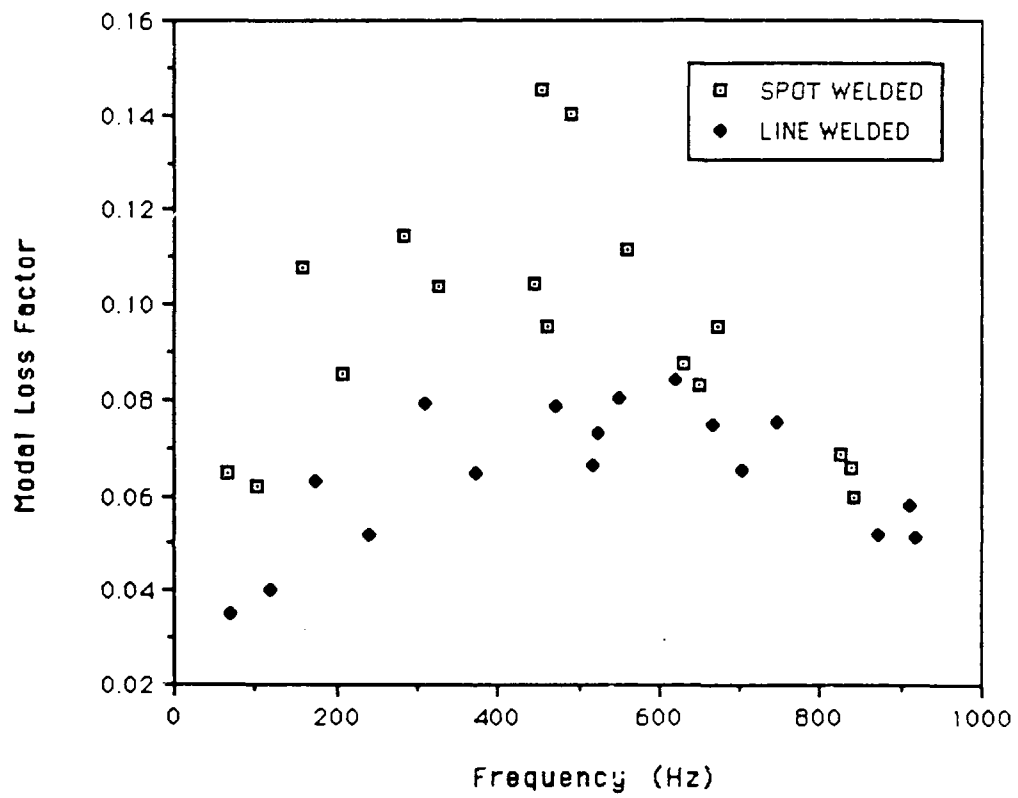


Figure 4.41. Comparison of Modal Loss Factor for Spot and Line Welded Floating Element at 15.6 °C.

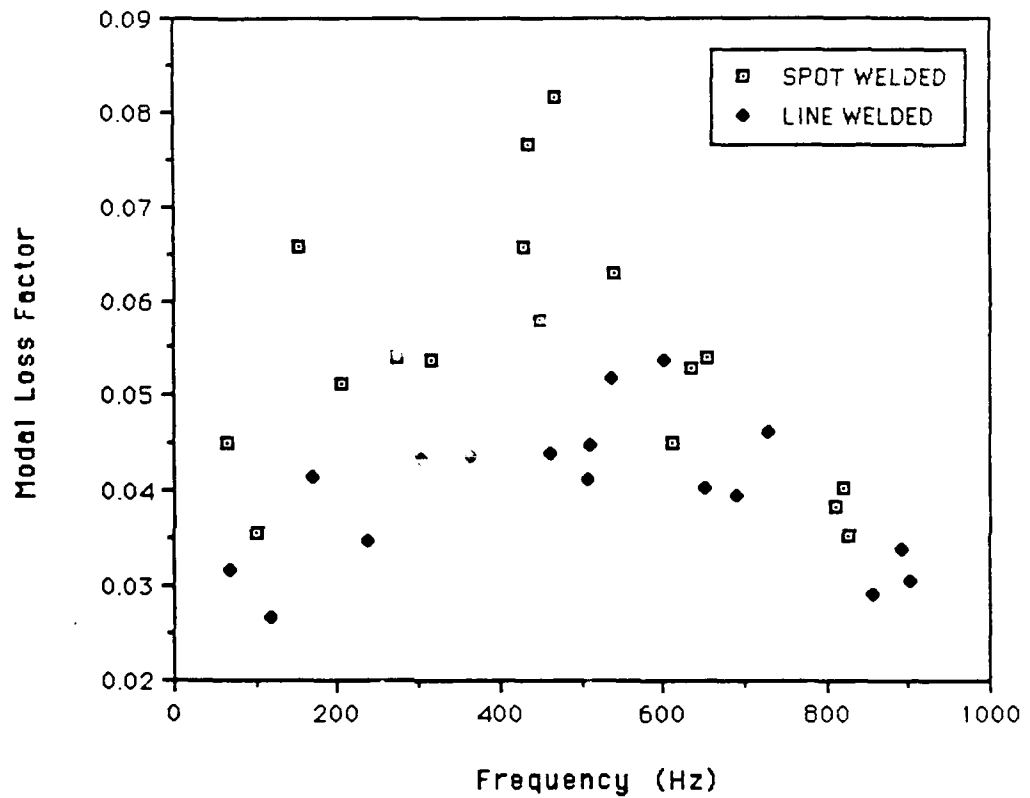


Figure 4.42. Comparison of Modal Loss Factor for Spot and Line Welded Floating Element at 26.7 °C.

V. CONCLUSIONS

In this paper I investigated the effectiveness of the Modal Strain Energy Method for the estimation of the modal loss factor of milled pocket plate and floating element plate which are two new configurations of the constrained viscoelastic layer damping treatments. Both of the experimental and estimated data show a very similar results as can be seen in Figure 5.1 and 5.2. It also shows that the new constrained viscoelastic layer damping treatments are extremely effective ways for the reduction of the vibration from structures.

Comparison with the previous works by Bateman [Ref. 2], shows that the double layer modal have the highest damping result. However, for welded configurations, the floating element concept is more effective to reduce the vibration than the pocket plate concept. The modal loss factor of the floating element plate in average is 25 percent over the pocket plate.

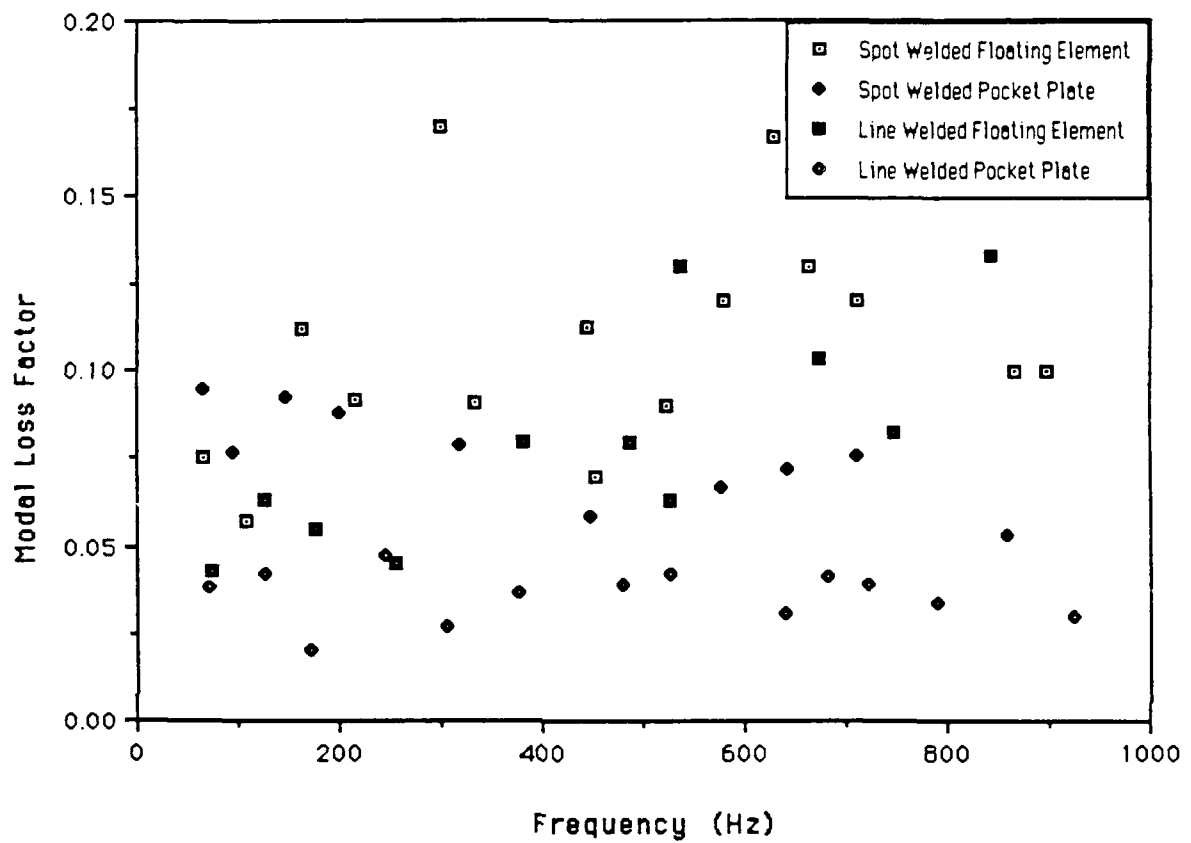


Figure 5.1. Comparison of Experimentally Measured Modal Loss Factor for the Four Damping Configuration

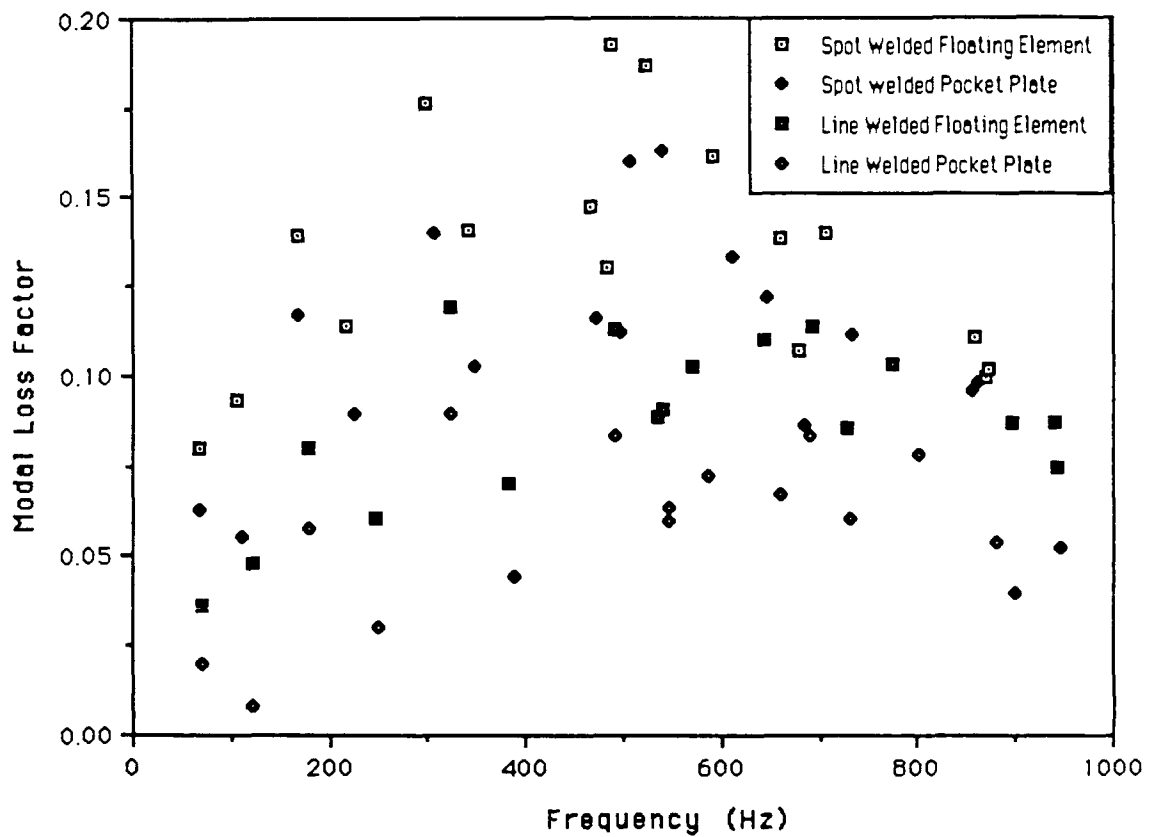


Figure 5.2. Comparison of Estimated Modal Loss Factors for the Spot and Line Welded Pocket Plate and Floating Element.

APPENDIX A. DESIGN DRAWINGS FOR THE MACHINING OF THE FLOATING ELEMENT AND POCKET PLATE CONFIGURATIONS

The drawings shown in Figures A.1 and A.2 [Ref. 2] were used to machine the pocket plate and floating element plate used in the experiments. These drawings are included to show the relation of the pocket for the ISD-112 to the cover plate and how the viscoelastic was protected from the heat of welding.

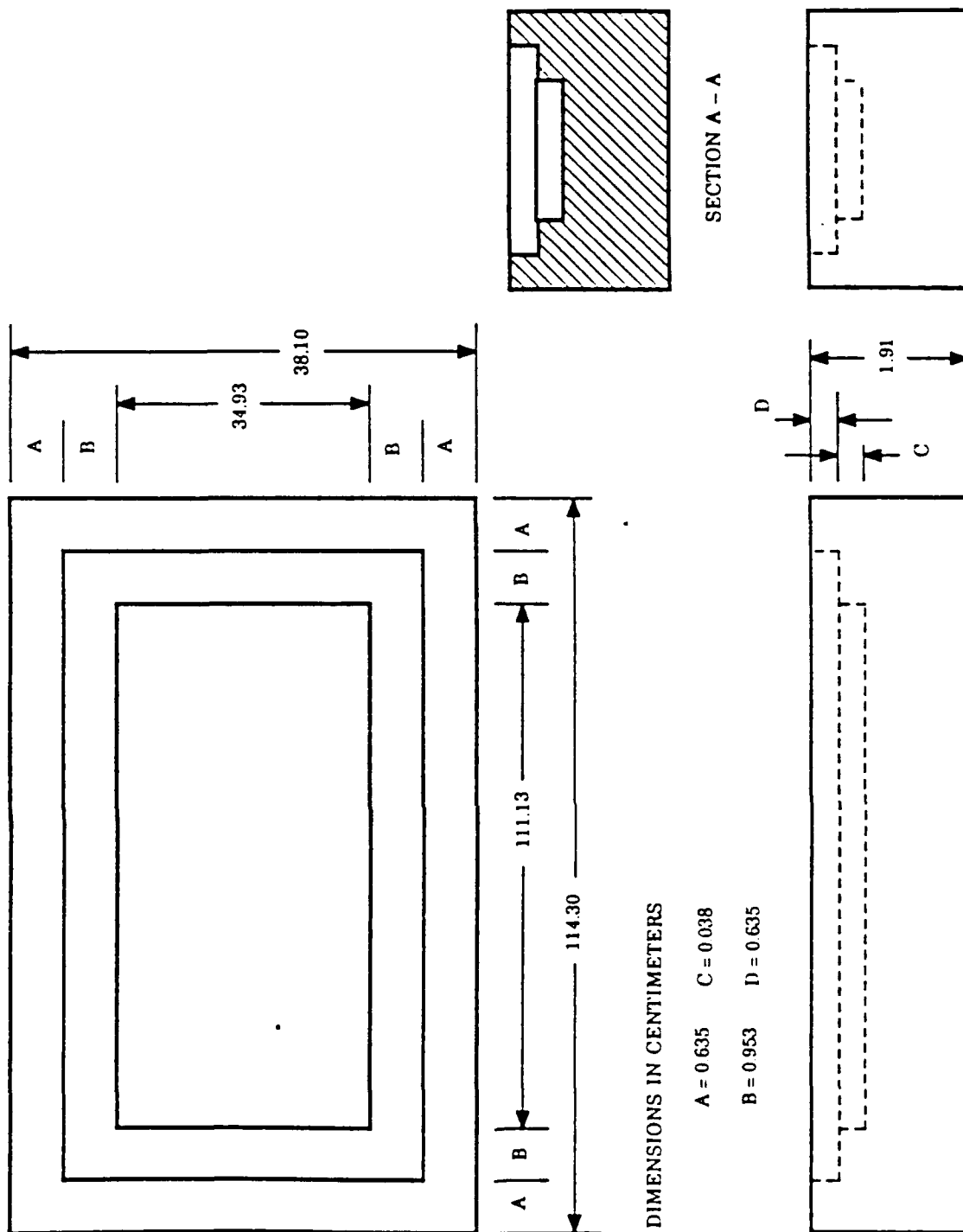


Figure A.1. Design Drawing of the Pocket Plate Configuration.

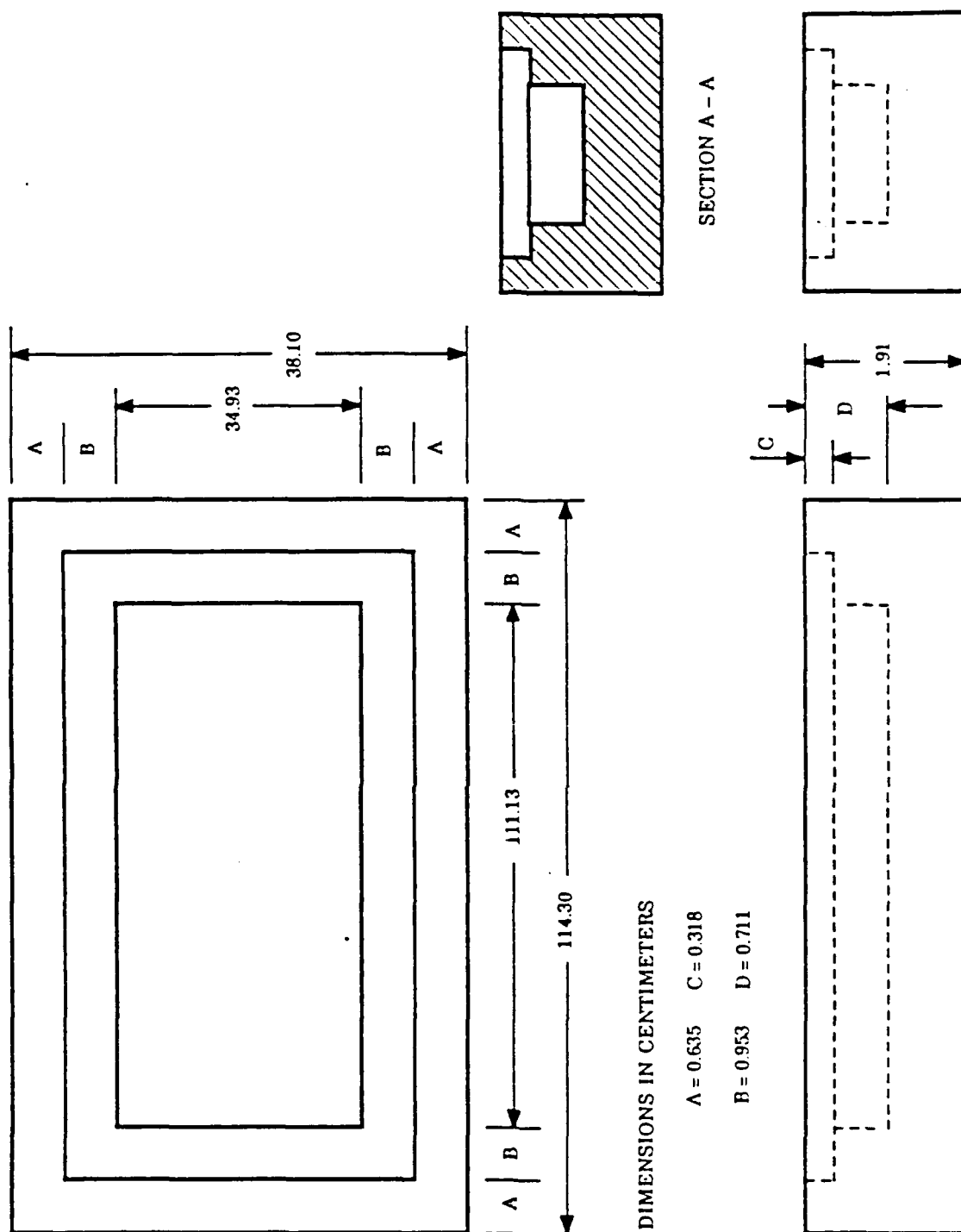


Figure A.2. Design Drawing of the Floating Element Configuration.

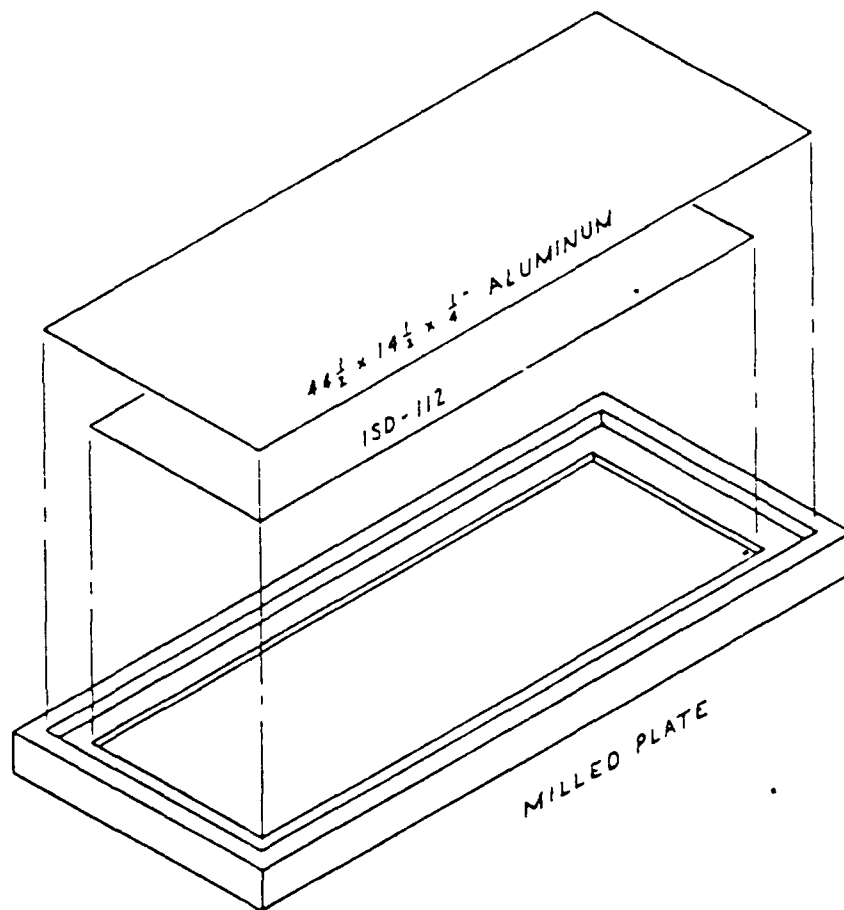


Figure A.3. General Arrangement of the Pocket Plate Configuration.

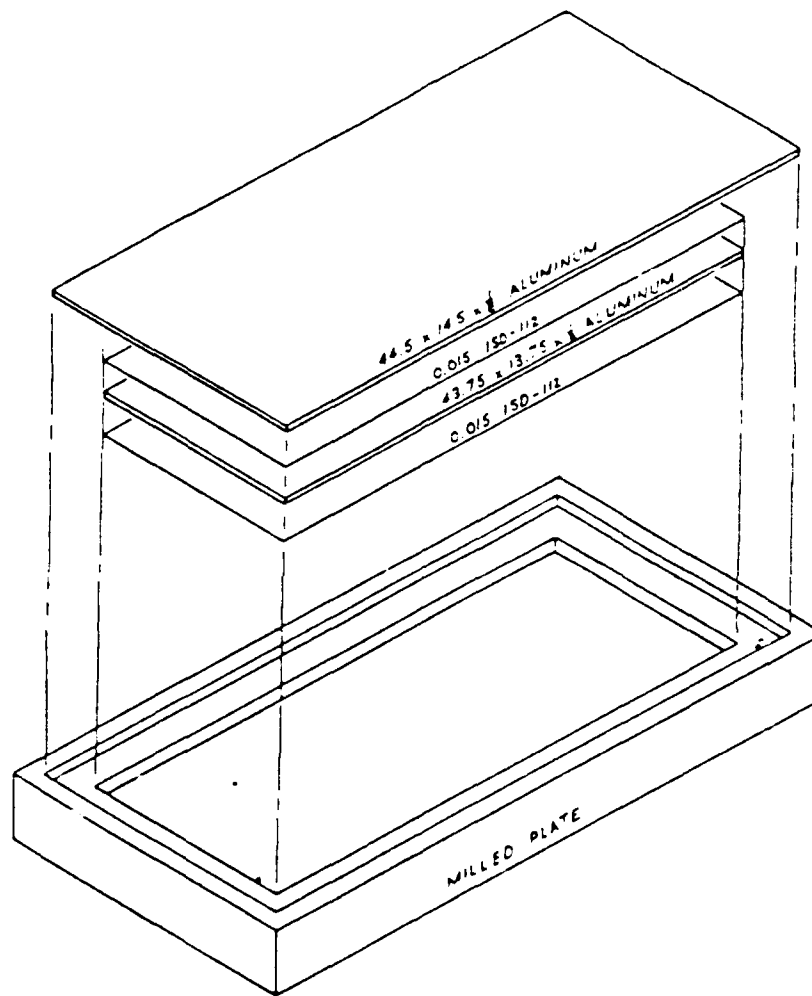


Figure A.4. Floating Element System Configuration.

APPENDIX B. SCALING AND GAIN FACTORS OF EXPERIMENTAL RESULTS FOR CORRECTING TO NASTRAN LEVEL

Experimental results are corrected to NASTRAN levels using the scaling factors and gains for the vibration generator, accelerometer, and charge amplifier used in the lab. These data are shown as follow:

Sensitivity of vibration generator	= 1060.0	pc/lb
Sensitivity of charge amplifier	= 1.060	pc/unit
Charge amplifier gain	= 10000.0	unit/volt
Accelerometer sensitivity	= 0.010	volt/G
Acceleration of gravity	= 386.0	in/sec/sec

APPENDIX C. REPRESENTATIVE MSC/NASTRAN DATA DECK FOR THE DAMPING CALCULATIONS

This data deck was used to compute the modal frequency response of the spot welded floating element plate configuration and is a representative sample of the MSC/NASTRAN decks used for the other finite element models. The values in the damping table are from a curve fit to the modal loss factors estimated from the modal strain energy method. Since the data deck for the normal mode and modal strain energy extraction is virtually identical to this deck, the Case Control deck commands for the normal mode analysis are included, but are commented out.

The OUTPUT request provides data for an x-y plot of the frequency response.

The units used in this deck are pounds, inches, and seconds.

GRID	16	5.00000	0.62500	0.47000
GRID	17	5.00000	4.06250	0.47000
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GRID	19	5.00000	10.9375	0.47000
GRID	20	5.00000	14.3750	0.47000
GRID	21	5.00000	15.0000	0.47000
GRID	22	9.37500	0.00000	0.47000
GRID	23	9.37500	0.62500	0.47000
GRID	24	9.37500	4.06250	0.47000
GRID	25	9.37500	7.50000	0.47000
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GRID	27	9.37500	14.3750	0.47000
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GRID	31	13.7500	4.06250	0.47000
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GRID	244	0.62500	15.0000	0.52667	
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GRID	246	0.63000	0.62500	0.52667	123456
GRID	247	0.63000	0.63000	0.52667	
GRID	248	0.63000	4.06250	0.52667	
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GRID	255	5.00000	0.62500	0.52667	

GRID	256	5.00000	0.63000	0.52667
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GRID	267	9.37500	7.50000	0.52667
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GRID	270	9.37500	14.3750	0.52667
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GRID	613	44.3700	15.0000	0.61000
GRID	614	44.3750	0.00000	0.61000
GRID	615	44.3750	0.62500	0.61000

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GRID	616	44.3750	0.63000	0.61000	123456
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GRID	636	0.00000	7.50000	0.62500	
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GRID	639	0.00000	14.3750	0.62500	
GRID	640	0.00000	15.0000	0.62500	
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GRID	645	0.62500	7.50000	0.62500	
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GRID	654	0.63000	7.50000	0.62500	123456
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GRID	657	0.63000	14.3750	0.62500	123456
GRID	658	0.63000	15.0000	0.62500	123456
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GRID	660	5.00000	0.62500	0.62500	
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GRID	681	13.7500	7.50000	0.62500	
GRID	682	13.7500	10.9375	0.62500	
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GRID	692	18.1250	14.3700	0.62500	123456
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GRID	709	26.8750	10.9375	0.62500	
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GRID	717	31.2500	7.50000	0.62500	
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GRID	721	31.2500	15.0000	0.62500	
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GRID	726	35.6250	7.50000	0.62500	
GRID	727	35.6250	10.9375	0.62500	
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GRID	731	40.0000	0.00000	0.62500	
GRID	732	40.0000	0.62500	0.62500	
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GRID	754	44.3750	10.9375	0.62500		
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GRID	757	44.3750	15.0000	0.62500		
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GRID	759	45.0000	0.62500	0.62500		
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GRID	761	45.0000	4.06250	0.62500		
GRID	762	45.0000	7.50000	0.62500		
GRID	763	45.0000	10.9375	0.62500		
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CQUAD4	6	1	6	13	14	7
CQUAD4	7	1	13	20	21	14
CQUAD4	8	1	20	27	28	21
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CQUAD4	10	1	34	41	42	35
CQUAD4	11	1	41	48	49	42
CQUAD4	12	1	48	55	56	49
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CQUAD4	26	1	50	57	58	51
CQUAD4	27	1	43	50	51	44
CQUAD4	28	1	36	43	44	37
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CQUAD4	37	1	16	23	24	17	-.235
CQUAD4	38	1	17	24	25	18	-.235
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CQUAD4	40	1	19	26	27	20	-.235
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CQUAD4	69	1	72	79	80	73	-.235
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+E 145	9	2							
CHEXA	146	3	93	102	104	95	2	9 E	146
+E 146	10	3							
CHEXA	147	3	95	104	105	96	3	10 E	147

+E 147	11	4							
CHEXA	148	3	96	105	106	97	4	11 E	148
+E 148	12	5							
CHEXA	149	3	97	106	108	99	5	12 E	149
+E 149	13	6							
CHEXA	150	3	99	108	109	100	6	13 E	150
+E 150	14	7							
CHEXA	151	3	108	126	127	109	13	20 E	151
+E 151	21	14							
CHEXA	152	3	126	135	136	127	20	27 E	152
+E 152	28	21							
CHEXA	153	3	135	144	145	136	27	34 E	153
+E 153	35	28							
CHEXA	154	3	144	153	154	145	34	41 E	154
+E 154	42	35							
CHEXA	155	3	153	162	163	154	41	48 E	155
+E 155	49	42							
CHEXA	156	3	162	171	172	163	48	55 E	156
+E 156	56	49							
CHEXA	157	3	171	180	181	172	55	62 E	157
+E 157	63	56							
CHEXA	158	3	180	189	190	181	62	69 E	158
+E 158	70	63							
CHEXA	159	3	189	198	199	190	69	76 E	159
+E 159	77	70							
CHEXA	160	3	198	216	217	199	76	83 E	160
+E 160	84	77							
CHEXA	161	3	216	225	226	217	83	90 E	161
+E 161	91	84							
CHEXA	162	3	214	223	225	216	82	89 E	162
+E 162	90	83							
CHEXA	163	3	213	222	223	214	81	88 E	163
+E 163	89	82							
CHEXA	164	3	212	221	222	213	80	87 E	164
+E 164	88	81							
CHEXA	165	3	210	219	221	212	79	86 E	165
+E 165	87	80							
CHEXA	166	3	209	218	219	210	78	85 E	166
+E 166	86	79							
CHEXA	167	3	191	209	210	192	71	78 E	167
+E 167	79	72							
CHEXA	168	3	182	191	192	183	64	71 E	168
+E 168	72	65							
CHEXA	169	3	173	182	183	174	57	64 E	169
+E 169	65	58							
CHEXA	170	3	164	173	174	165	50	57 E	170
+E 170	58	51							
CHEXA	171	3	155	164	165	156	43	50 E	171
+E 171	51	44							
CHEXA	172	3	146	155	156	147	36	43 E	172
+E 172	44	37							
CHEXA	173	3	137	146	147	138	29	36 E	173
+E 173	37	30							
CHEXA	174	3	128	137	138	129	22	29 E	174
+E 174	30	23							
CHEXA	175	3	119	128	129	120	15	22 E	175
+E 175	23	16							
CHEXA	176	3	101	119	120	102	8	15 E	176
+E 176	16	9							
CHEXA	177	6	112	121	122	113	9	16 E	177

+E 177	17	10							
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+E 186	32	25							
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CHEXA	188	6	133	142	143	134	26	33 E	188
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+E 195	47	40							
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+E 196	48	41							
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+E 197	52	45							
CHEXA	198	6	158	167	168	159	45	52 E	198
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+E 199	54	47							
CHEXA	200	6	160	169	170	161	47	54 E	200
+E 200	55	48							
CHEXA	201	6	166	175	176	167	51	58 E	201
+E 201	59	52							
CHEXA	202	6	167	176	177	168	52	59 E	202
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CHEXA	203	6	168	177	178	169	53	60 E	203
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CHEXA	204	6	169	178	179	170	54	61 E	204
+E 204	62	55							
CHEXA	205	6	175	184	185	176	58	65 E	205
+E 205	66	59							
CHEXA	206	6	176	185	186	177	59	66 E	206
+E 206	67	60							
CHEXA	207	6	177	186	187	178	60	67 E	207

+E 207	68	61								
CHEXA	208	6	178	187	188	179	61	68 E	208	
+E 208	69	62								
CHEXA	209	6	184	193	194	185	65	72 E	209	
+E 209	73	66								
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+E 210	74	67								
CHEXA	211	6	186	195	196	187	67	74 E	211	
+E 211	75	68								
CHEXA	212	6	187	196	197	188	68	75 E	212	
+E 212	76	69								
CHEXA	213	6	193	202	203	194	72	79 E	213	
+E 213	80	73								
CHEXA	214	6	194	203	204	195	73	80 E	214	
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+E 215	82	75								
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+E 226	154	145								
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+E 230	190	181								
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+E 238	219	210								
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+E 268	161	152							
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+E 269	167	158							
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+E 270	168	159							
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+E 271	169	160							
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+E 272	170	161							
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+E 273	176	167							
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+E 274	177	168							
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+E 275	178	169							
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+E 276	179	170							
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+E 277	185	176							
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+E 278	186	177							
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+E 280	188	179							
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+E 282	195	186							
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+E 283	196	187							
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+E 284	197	188							
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+E 286	204	195							
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+E 288	206	197							
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+E 295	262	244							
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+E 296	271	262							
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ENDDATA

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