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DYNAMIC PHASE PLOTTING*

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ABSTRACT

This paper describes a system being developed for resolving accelerometer signals from sine-wave vibration tests into coincident and quadrature components for the unambiguous rendition of phase relationships. In the field of sine-wave vibration testing, continuous plotting of response amplitude versus frequency is commonly accomplished without the attendant phase information.

With commercially available equipment, phase is a difficult parameter to plot on analog plotting systems. The use of complex vectors (Co and Quad phasors) eliminates many of the difficulties of phase measurement and facilitates analog plotting. Phasor information can be transformed into phase information by computer processing.

Typical results for the system at its present stage of development are illustrated and discussed.

One of the significant, but unexploited, parameters in the measurement and analysis of sine-wave vibration test data is phase. The analysis of test data has generally been limited to acceleration response amplitudes with no indication of phase relationships. At the Magnetic Tape Playback Center for the Environmental Test Laboratories, analog plots of acceleration versus frequency are regularly produced for sine-wave sweeps of the shakers from accelerometer responses recorded on magnetic tape. Except for mechanical impedance or mobility measurements, phase has largely been ignored.

There are several reasons for this situation. Phase is not an easy parameter to measure or process with analog equipment. The commercially available phase meter indicates phase as a function of the time between zero axis crossings by the input signals. Thus, the measurement is sensitive to amplitude, influenced by noise, and severely restricted in range. A discontinuity occurs when one input, or both, falls below the threshold magnitude. The scale is awkward because it covers a range of 360 degrees and then repeats. An ambiguous region exists, therefore, at each end of the scale, and there is no indication of phase differences beyond a single cycle of frequency. These difficulties apply equally to analog phase plotting and make it confusing at best.

As in mathematics, and specifically in network analysis, phase relationships are described and traced by means of complex variables and phasors

(vectors) which have both magnitude and direction. Applying complex notation to the vibration response amplitude, and its phase angle referred to the input, one obtains

$$g \angle \theta = C + jQ,$$

where C is the phasor component coincident (Co) with the input, and Q is the phasor component in quadrature (Quad) with the input (or reference), Figure 1. These are the polar and cartesian coordinates of the vibratory response, where

$$g = \sqrt{C^2 + Q^2} \quad \text{and } \theta = \arctan Q/C.$$

Enlightened use of the Co and Quad phasors should enable one to trace phase relationships without ambiguity.

Based on the foregoing, the Magnetic Tape Playback Center has abandoned efforts to plot phase directly and is developing a system whereby dynamic phase relationships can be followed by means of the Co and Quad components. In development is a subsystem which will resolve accelerometer signals into their Co and Quad phasors referred to some meaningful reference signal having the same frequency. These phasors can be plotted on the existent vibration plotting system or digitized for computer processing to obtain phase plots, transfer functions, etc. A basic phasor resolving subsystem, for ten signal and two reference channels, was developed for Sandia by ADYU Electronics around the circuitry of their Type 1034 Synchronous Filter and Type 308 Component

Resolver. The general sequence of operations for the reference channels and one signal channel is diagrammed in Figure 2.

The frequency reference is applied to the carrier generator and the phase reference to the input amplifier of the reference channel. Output from the carrier generator is a synchronized carrier voltage having frequency $F_C + F_R$, which is input to all balanced mixers. In the reference channel the phase reference is also input to the balanced mixer, which then outputs the three frequencies F_R, F_C, and $F_C + 2F_R$. The crystal bandpass filter passes only the carrier oscillator frequency, F_C, which has the same phase as the reference input and is proportional in amplitude. After a final phase and proportionality adjustment in the next amplifier stage, the reference signal is fed to reference inputs to the coincidence resolver and, through a 90° phase shifter, to the quadrature resolver.

The signal input, E_S, is subjected to the same sequence of operations (except the 90° phase shift) as the phase reference, E_R, and is then applied to the Co and Quad resolver inputs. The resolvers are bridges which, when excited by the Co and Quad reference voltages, allow only those components of the signal that are in phase with the exciting voltage to be rectified. Thus, the dc output of the Co resolver is proportional to $E_S \cos \theta$, and that of the Quad resolver is proportional to $E_S \sin \theta$ (see Figure 1) when E_R is held constant within ± 1 db.

For plotting the transfer characteristics of most devices, the input voltage is normally held constant and can, therefore, be used for the phase

reference as well as the frequency reference. For vibration tests, however, the input acceleration is seldom constant over the entire sweep frequency range. Therein lies the major disadvantage of the basic subsystem for direct analog plotting of the Co and Quad phasors. The frequency reference voltage derived from the shaker drive oscillator has constant amplitude and is presently being used for both frequency and phase reference. Thus, the phasor outputs are presently referred to the shaker drive voltage while efforts to achieve satisfactory automatic gain circuitry for the phase reference channel continue. This presents no particular disadvantage for computer processing of phase angles since the phase angle between the drive voltage and the acceleration input can be subtracted out for each sample frequency.

Figures 3, 4, and 5 illustrate the phase relationship between the sweep oscillator output voltage and the acceleration input for a vibration test of a relatively simple structure. As the frequency increases, the acceleration input to the test fixture progressively lags behind the drive coil voltage in a typical normal mode, single-degree-of-freedom response. This is shown by the circular clockwise pattern of the Nyquist plot of Figure 3, by the progressive relationship between the Co and Quad phasors of Figure 4, and by the computed phase angle curve of Figure 5. Input acceleration versus frequency is plotted in Figure 6 and is always equal to the square root of the sum of the squared phasors regardless of which signal is used for phase reference. On Figures 4, 5, and 6, there is a definite noise pattern below 20 Hz. The tracking filter in the phasor subsystem has a bandpass of plus and minus 20 Hz,

which will pass distortion components at frequencies below 20 Hz, and the noise swings will not be damped out by the digitizer as they would be by an analog plotting system. This noise is eliminated by playing the taped record back at twice the record tape speed, which effectively reduces the filter bandpass to plus and minus 10 Hz.

Figures 7, 8, and 9 illustrate the acceleration response at a location on the test item. Figure 7 shows the Co and Quad phasors referred to the drive voltage while Figure 8 shows the computed phase angle of the response referred to the input. The analog plots are duplicates of these digital plots and are, therefore, not included here. A comparison of the response phasors of Figure 7 with the input phasors of Figure 4 clearly indicates the critical frequencies apparent on the response amplitude plot of Figure 9 compared to the input amplitude of Figure 6.

As users become experienced in the analysis of vibration data by means of the Co and Quad phasors, the phasor plotting system being developed should prove valuable for modal studies and as an additional tool for the evaluation of vibratory responses and transfer functions.

LIST OF FIGURES

1. Typical Phasor Diagram

2. Block Diagram of Phasor Channel

3. Nyquist Plot of Input Phasors

4. Input Phasor Plot vs Frequency

5. Input Phase Plot vs Frequency

6. Input Acceleration vs Frequency

7. Response Phasor Plot vs Frequency

8. Response Phase Referred to Input

9. Response Acceleration vs Frequency

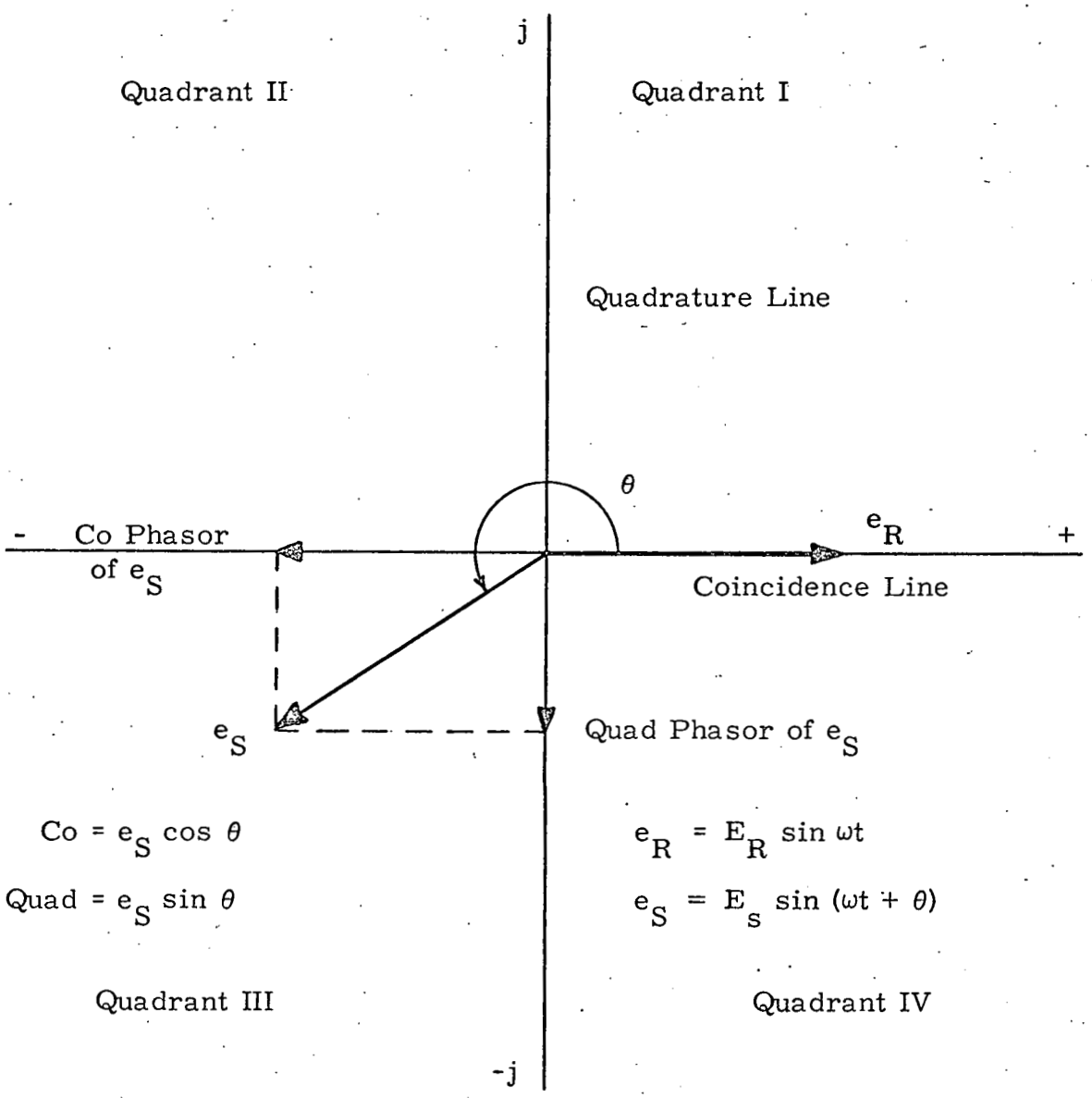

Figure 1. Typical Phasor Diagram

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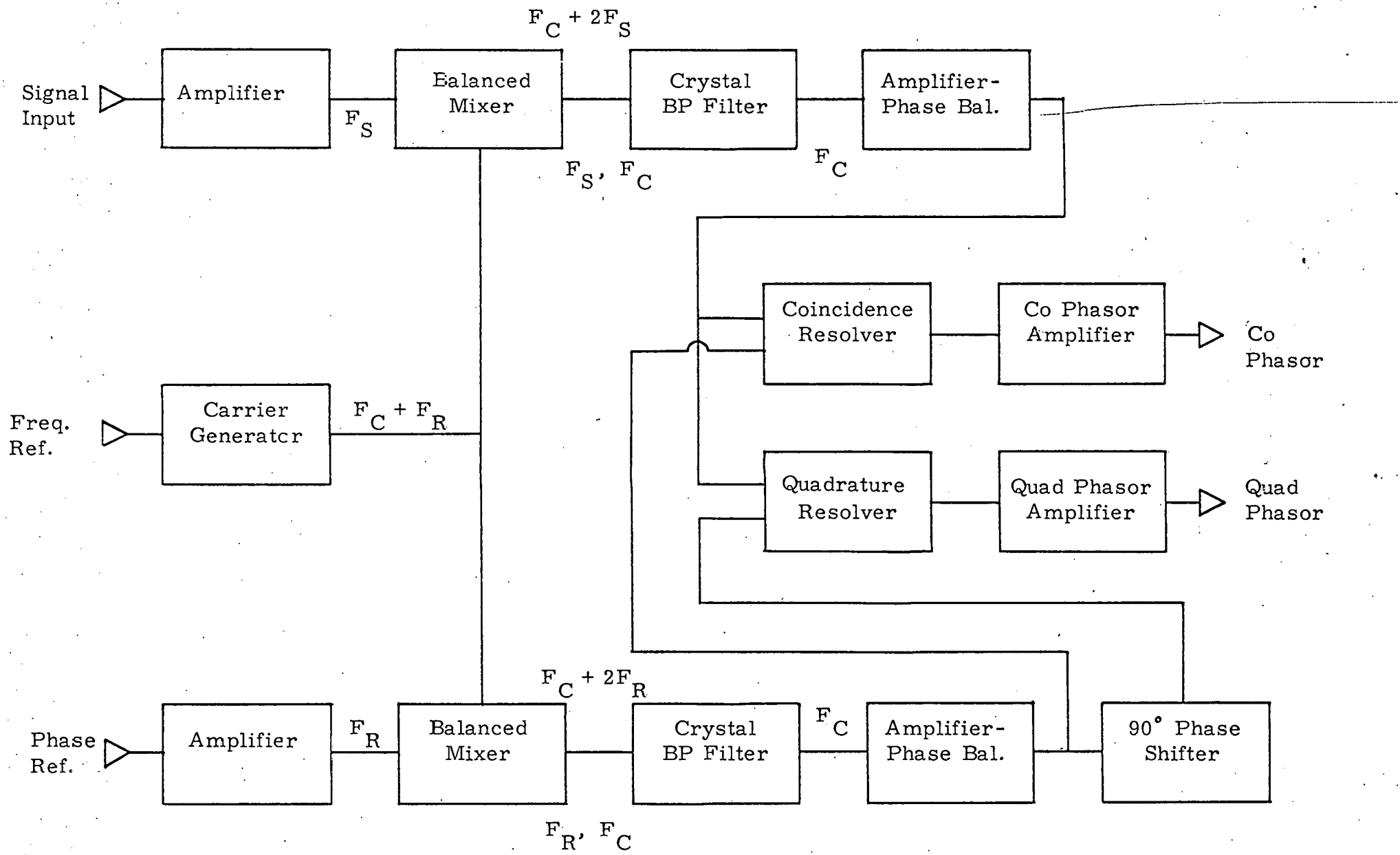

Figure 2. Block Diagram of Phasor Channel

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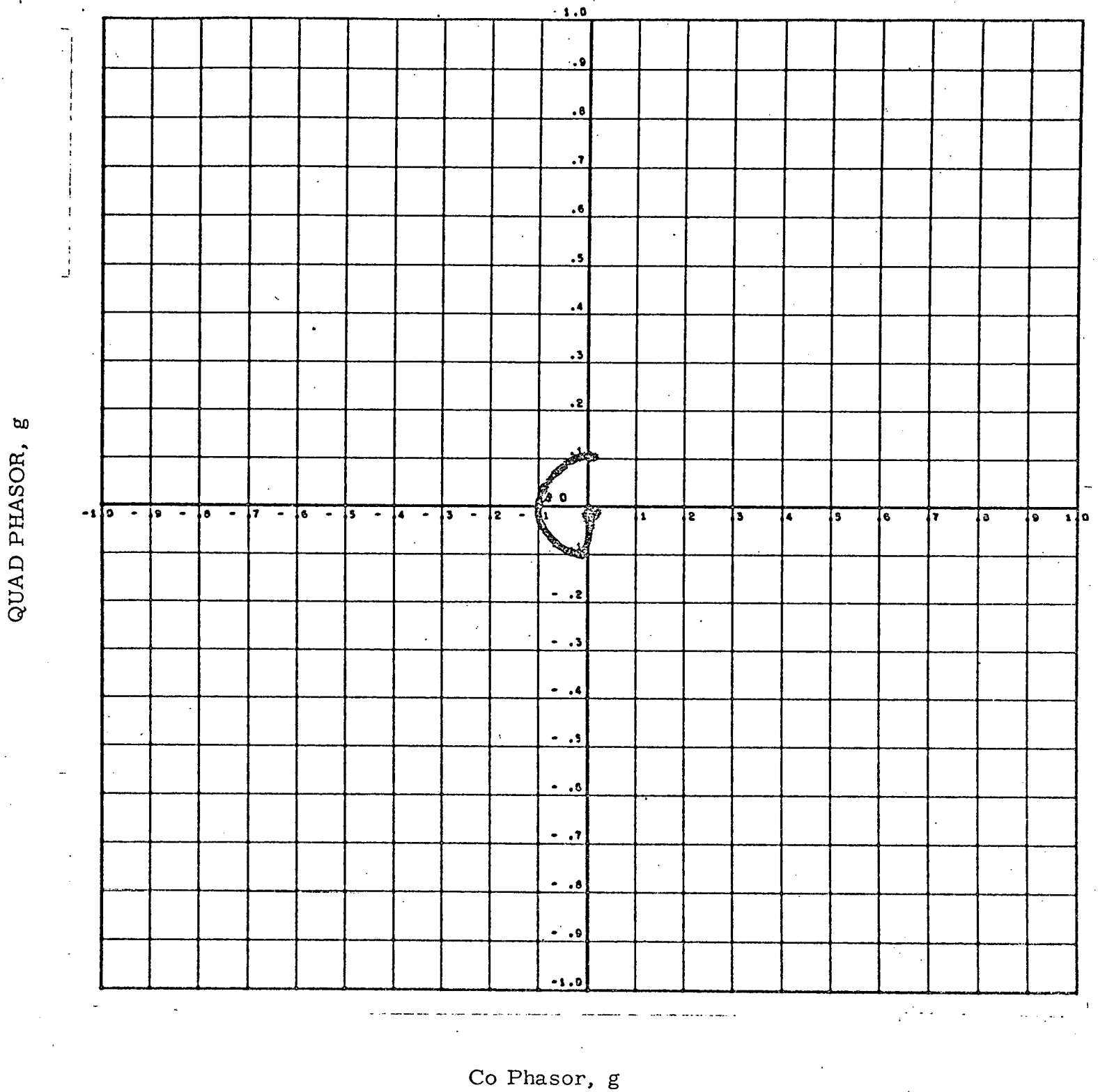

Figure 3. Nyquist Plot of Input Phasors

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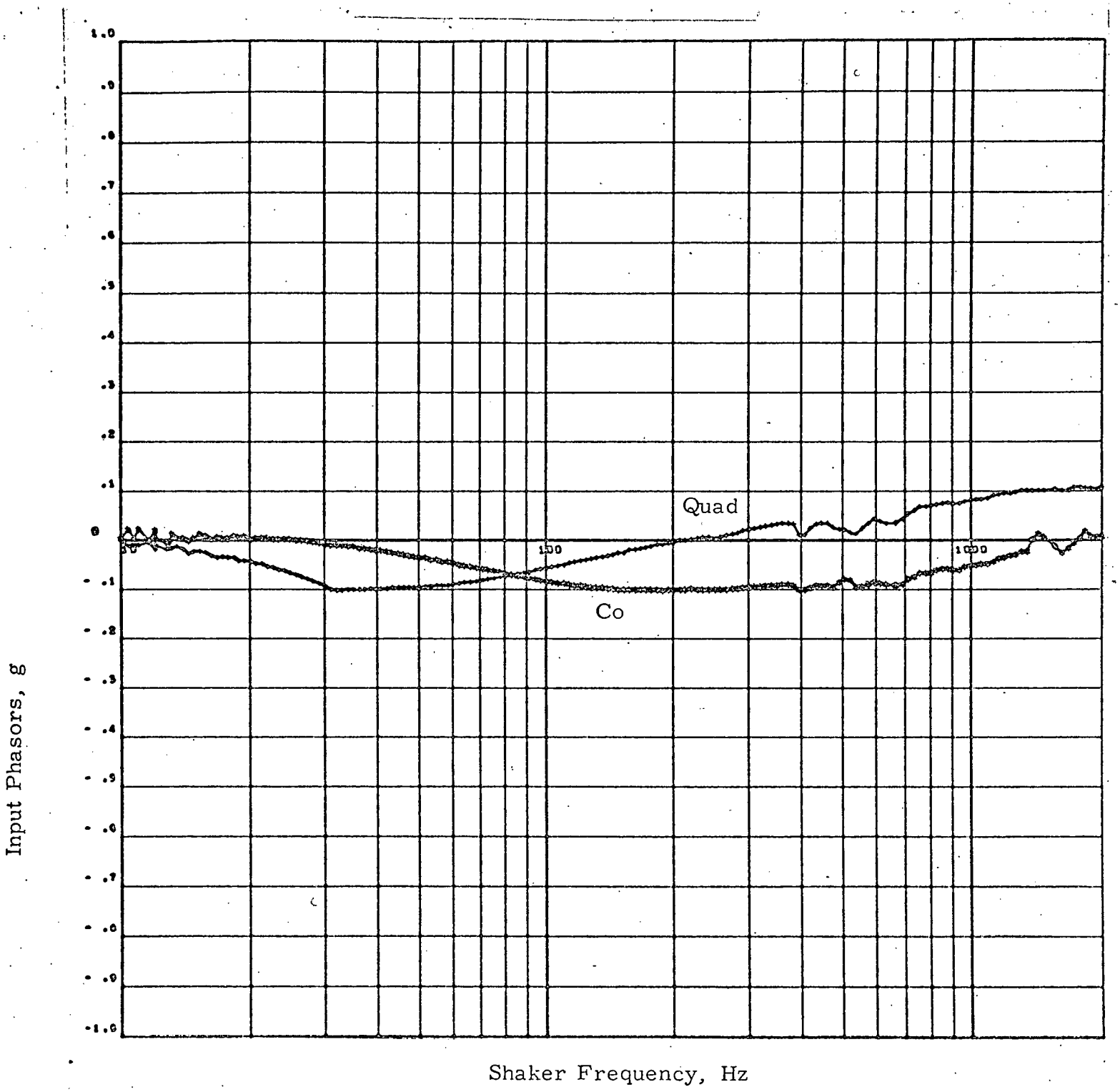

Figure 4. Input Phasor Plot vs Frequency

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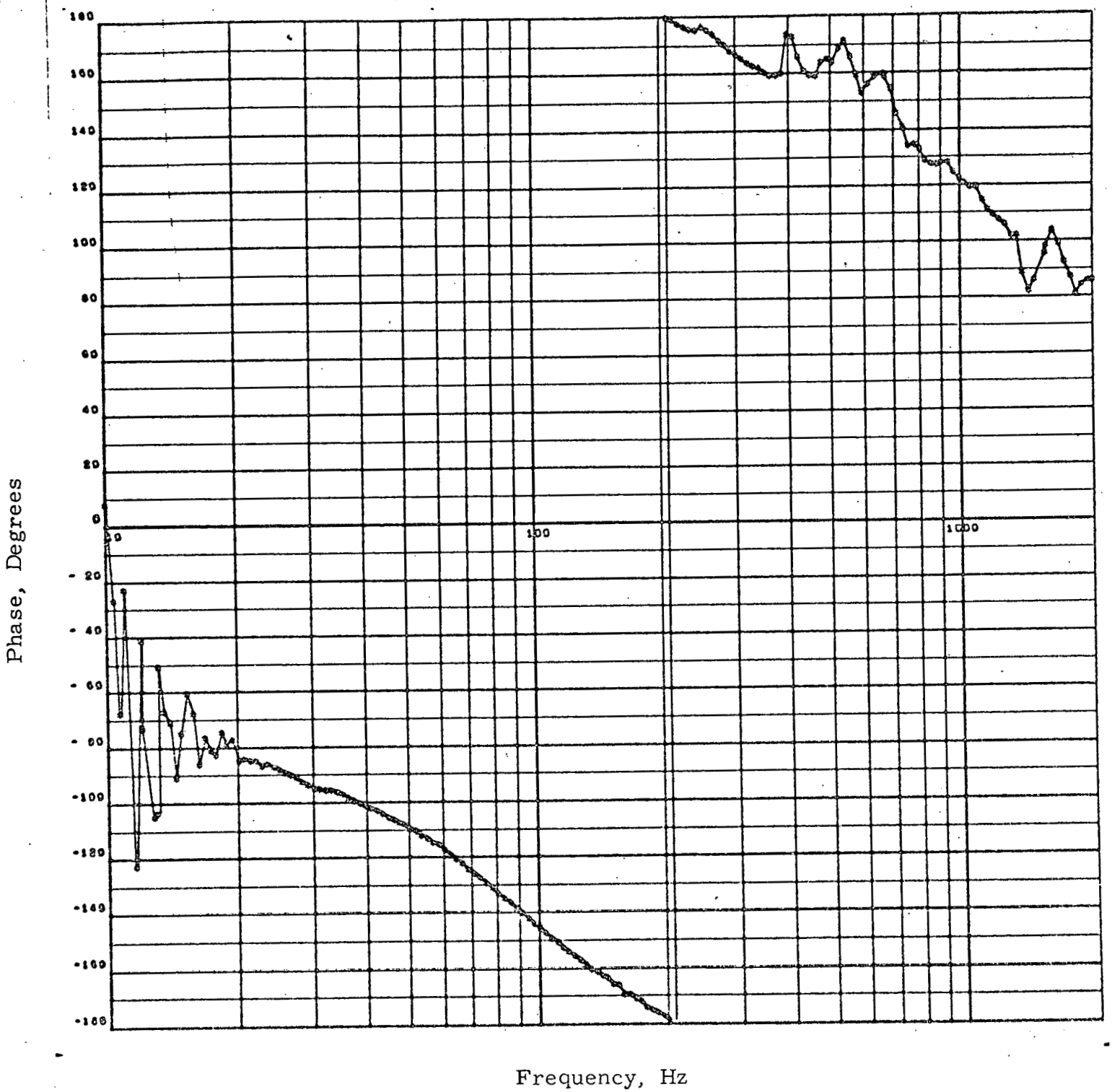

Figure 5. Input Phase Plot vs Frequency

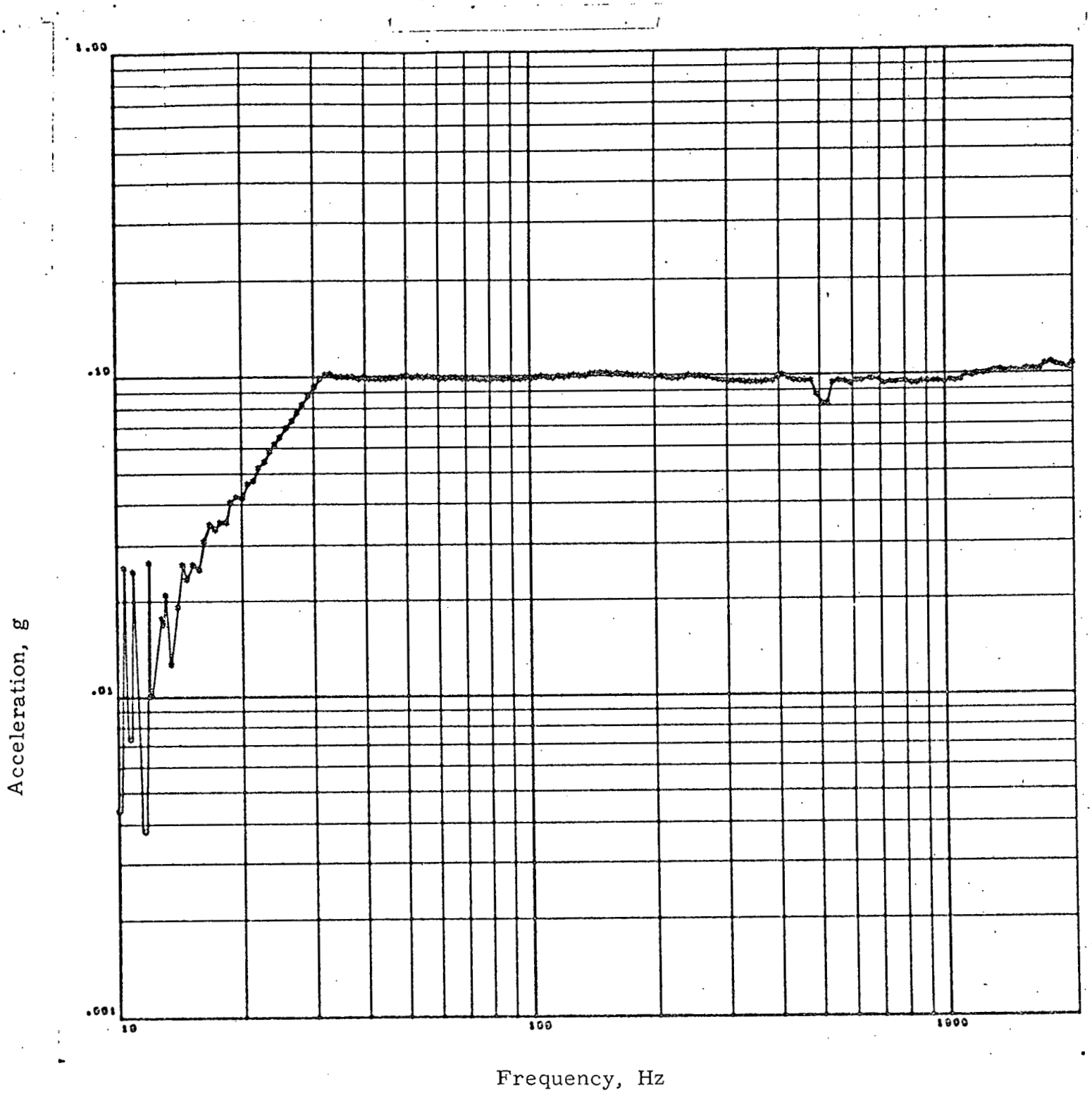

Figure 6. Input Acceleration vs Frequency

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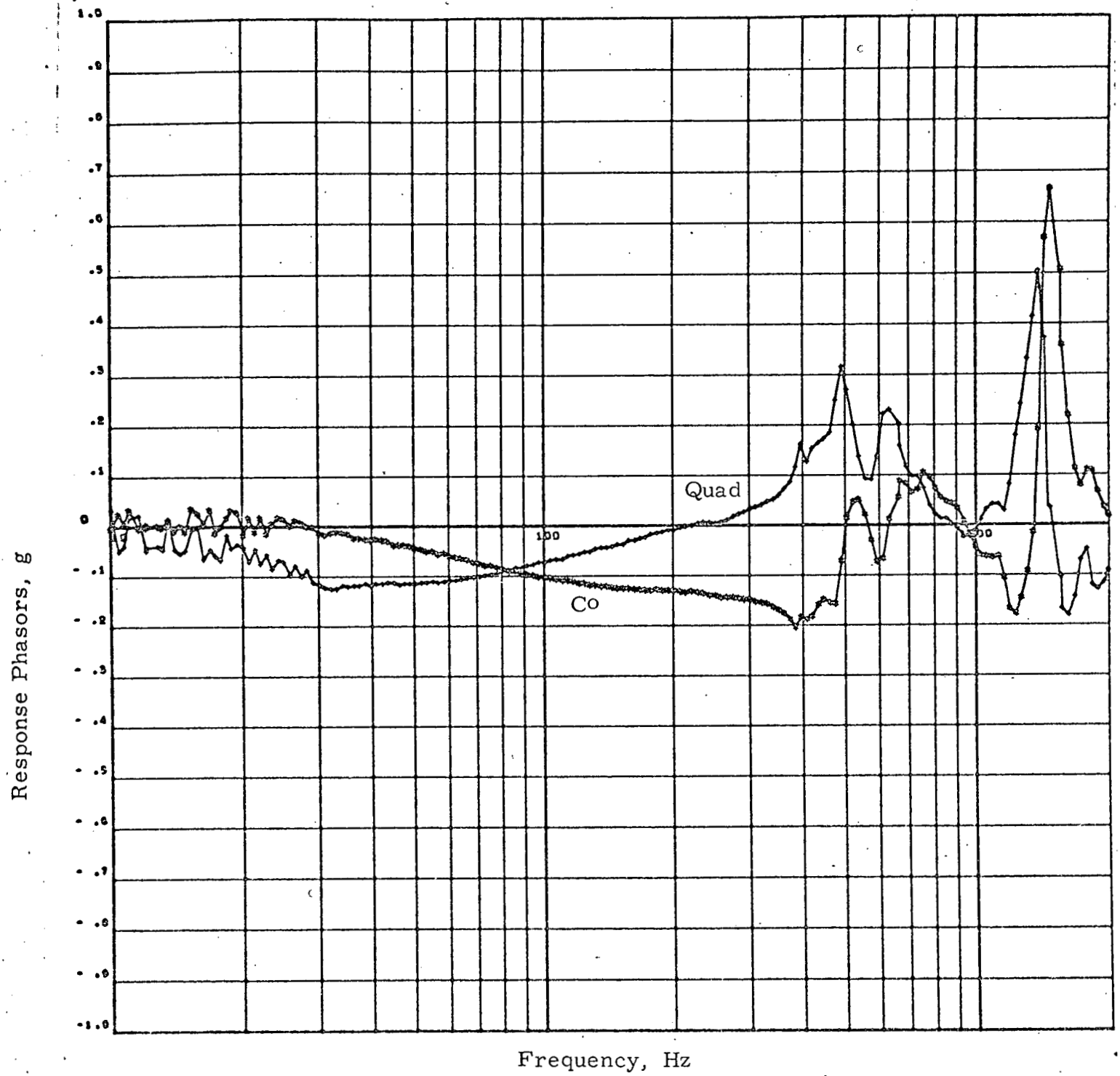

Figure 7. Response Phasor Plot vs Frequency

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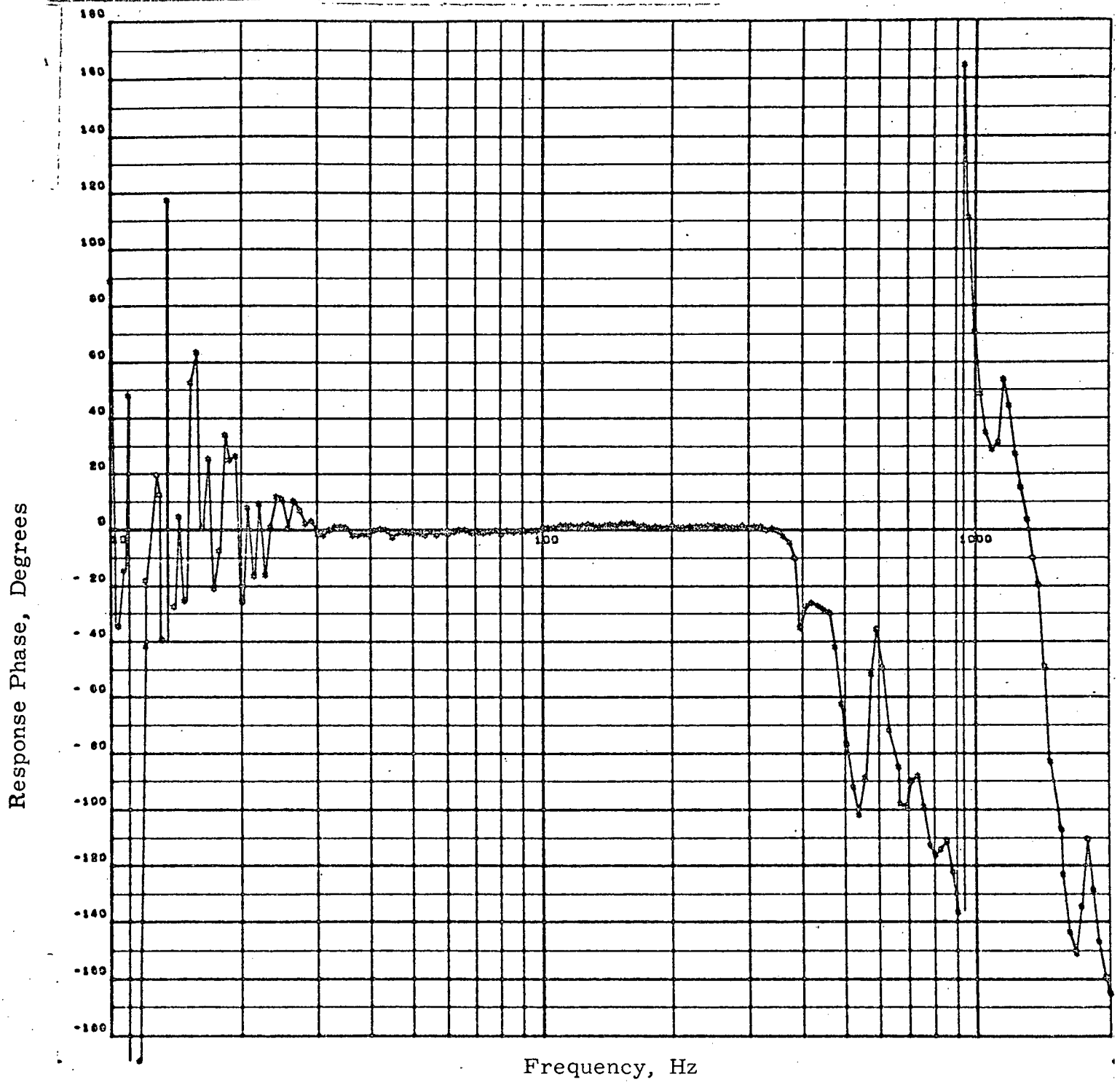

Figure 8. Response Phase Referred to Input

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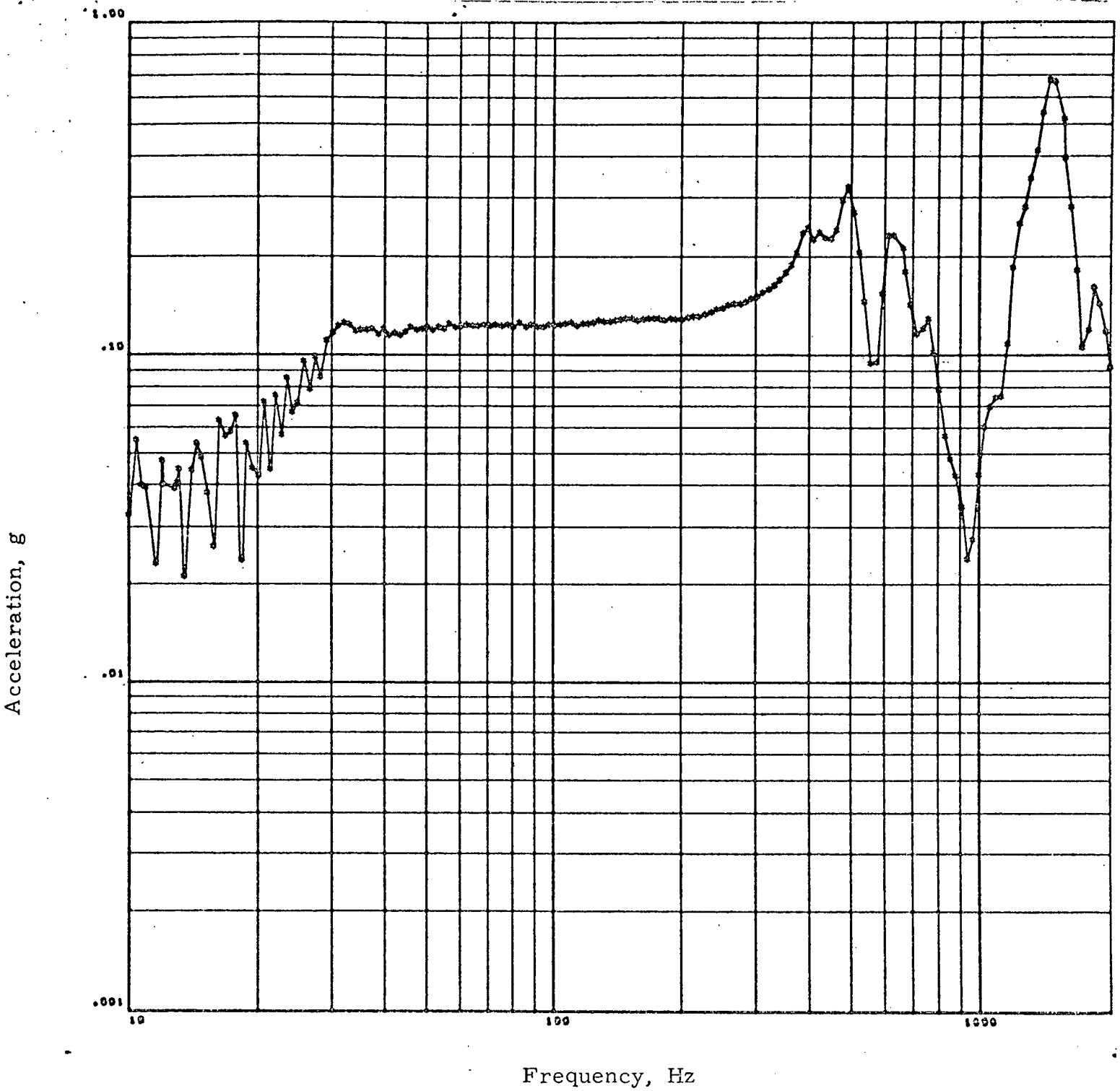

Figure 9. Response Acceleration vs Frequency

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