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SONIC PRESSURE VESSEL SENSOR

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Abstract
A sensor method and apparatus are described for measuring the pressure of a gas within a sealed commercial pressure vessel mounted into an assembly. A sonic transducer is used to apply an oscillating force to the surface of a vessel. The frequency of the sonic wave is swept through a range which caused resonant vibrations of the gas in the vessel. A receiving transducer measures the amplitude of the resultant vibration at the vessel surface and reveals the resonant frequency of the gas at peaks in the amplitude of the sweep. The resonant frequency obtained depends upon the composition of the gas, its pressure and temperature and the shape of the confining vessels. These relationships can be predetermined empirically so that the pressure inside the vessel can be calculated when the composition of the gas, its temperature and shape of the confining vessel are known. The output of the receiver is fed into a computer which is programmed to calculate the pressure based upon these predetermined relationships which are stored in the computer.

INTRODUCTION

Several techniques have been reported in the past literature for measuring various properties of gas filled pressure vessels. These include acoustic emission [1] and angle beam ultrasonic methods [2]. In other studies a combination of acoustic and microwave resonances were used to study the properties of a precisely machined spherical shell filled with various fluids including gases and metallic fluids such as mercury [3].

This report describes a sensor method with detailed results of the use of externally excited gas resonances for measuring the pressure of gas inside sealed commercial containers. A preliminary report of the principal idea of using gas resonance was given elsewhere [4].

The specific objective here was to examine the feasibility of using this approach to measure the pressure of helium inside the spheroidal helium vessel when part of a commercial assembly with straps and pneumatic gear. This approach appears promising, since the accuracy of pressure measurement is estimated conservatively at 100 psi.

To accomplish the objectives of the program a single free-standing pressure vessel bottle was adapted to an existing pressurization system. A thermocouple for measuring gas temperature and a miniature microphone for measuring sound pressure levels were installed in the neck of the bottle immediately below the machined fitting. A precision bourdon tube pressure gauge was used to measure gas pressure. Using this system it was possible to perform preliminary tests, which resulted in the positive identification of a useful gas resonance peak, whose frequency shifted systematically with pressure. It was also possible to calibrate the frequency of the resonance as a function of gas pressure to 7500 psi and temperature from 0 to 100°F. The assembly described above, with a single unclamped vessel resting on a ring-like base, will be referred to in this report as the "free-standing vessel." The results of these studies are described in Section 2.

STUDIES OF THE FREE-STANDING VESSEL

A block diagram of the instrumentation used to study the resonances of the free-standing vessel is shown in Fig. 1. The transducer used to excite the resonant vibrations was a 7-element stack of extension-polarized lead zirconate titanite. Each element was a square plate 0.150 in. thick and 7/16 in. on a side. Plates were bonded together using a conducting silver-filled epoxy. This transmitter was bonded to the surface of the bottle using a pliable adhesive. The receiver was a piezoelectric element removed from a commercially manufactured microphone. It was adhesively bonded to a permanent magnet that was coupled magnetically to the surface of the bottle.

Broad-band sweeps showed that the spectrum was cluttered with many resonances at frequencies above approximately 5500 Hz. In most cases it was not possible to distinguish between the gas resonances, which shifted in frequency with changes in gas pressure or gas composition, and had a relatively high "Q"; and mechanical resonances of the vessel wall, which remained more-or-less stationary and had a relatively low "Q". Two gas resonance peaks were clearly resolved at relatively low frequencies when the vessel was filled with nitrogen gas at ambient pressure. The lowest frequency peak at 1224 Hz corresponded to the $l = 1$, n = 1 mode, and the other at 3461 Hz corresponded to the $l = 1$, n = 2 mode. The former represents the lowest order mode possible, corresponding to a transverse motion of gas within the bottle. The latter corresponds to the lowest order mode with spherical symmetry.

Because the velocity of sound in helium is much higher than it is in nitrogen, all resonances were shifted to higher frequencies when the nitrogen was replaced with helium. The resonant frequency of the $l = 1$, n = 1 mode at ambient pressure increased to approximately 3550 Hz. The resonance of the $l = 1$, n = 2 mode was not observed because it was obscured by a multitude of structural resonances at higher frequencies.

Fortunately, however, the lowest order gas resonance occurred in a window of frequency significantly below the structural resonances. The frequency of the resonance has been measured as a function of pressure and temperature. Calibration curves at several different temperatures are shown in Fig. 2. Table 1 indicates that the frequency of the measured resonance is in excellent agreement with theoretical calculations.

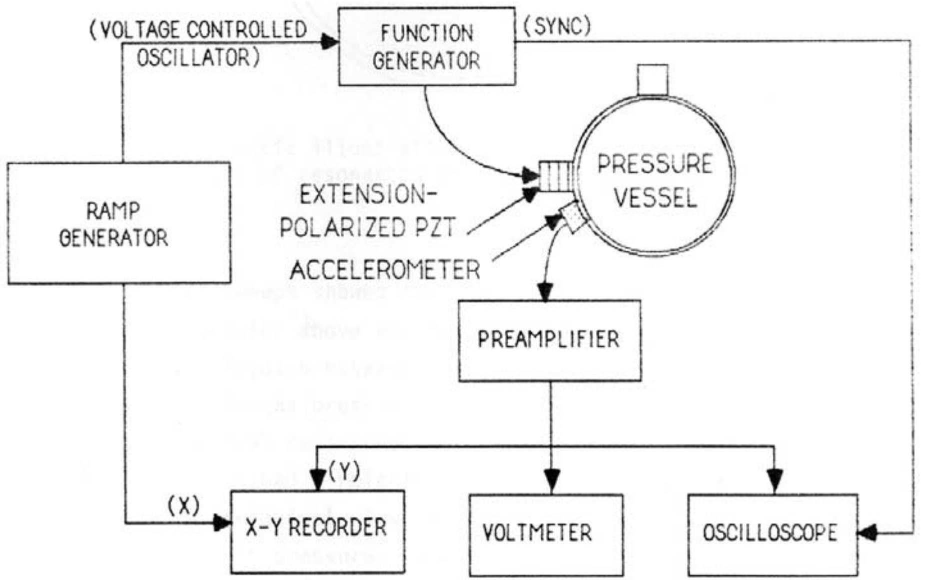

Figure 1 – Block diagram of instrumentation used to monitor resonances in both the free-standing vessel and the complete system

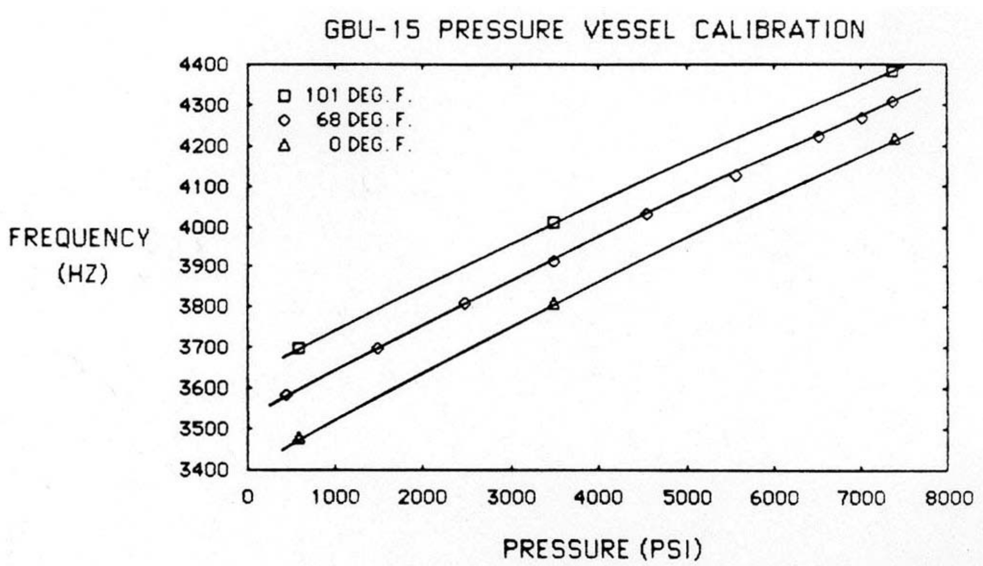

Figure 2 – Frequency-pressure calibration curves at several different temperatures

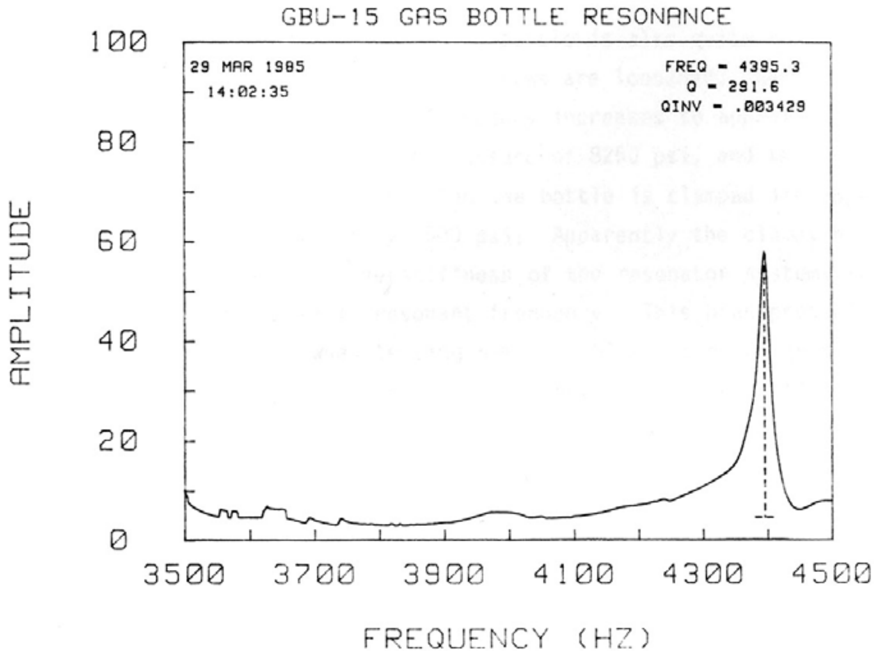

Figure 3 – Trace of resonant vibrations between 3500 Hz and 4500 Hz, the window of interest for a gas pressure sensor

Table 1 – Comparison of Measured Vibration Frequencies at Several Pressures with those Calculated on the Basis of Theory, Assuming a Spherical Vessel with a Radius of 9.45 cm

Pressure (psi)	Sound Velocity in He (M/S)	Predicted Frequency (Hz)	Observed Frequency (Hz)
500	1016	3564	3611
700	1024	3592	3622
1000	1033	3625	3664
2000	1070	3758	3774
2500	1080	3791	3810
4600	1134	3978	4053
7000	1195	4192	4284

CONCLUSIONS

By a combination of theory and experiment, we have arrived at the following conclusions concerning the feasibility of measuring the pressure of a commercial pressure vessel system using externally excited and externally monitored gas resonances:

1. A closely-spaced set of gas resonances (designated by $l = 1$ and $n = 1$) can be observed with an adequate signal-to- noise ratio.

2. These resonances are far removed from structural resonances, at least for pressures below 8000 psi.

3. The pressure dependence of the resonances is sufficiently strong that the frequency measurements can be used to infer the pres- sure with sufficient accuracy for testing purposes.

REFERENCES

[1| ASNT Standard E 2191, Standard Test Method for Examination of Gas-Filled Filament-Wound Composite Pressure Vessels Using Acoustic Emission.

[2] ASNT E 2223, Standard Practice for Examination of Seamless, Gas-Filled, Steel Pressure Vessels Using Angle Beam Ultrasonic.

[3] Moldover, M. R., James B. Mehl and Martin Greenspan. "Gas-filled spherical resonators: theory and experiment. J. Acoustical Society of America 79, 253-272 (1986).

[4] Tittmann, B. R., John M Richardson, James R. Bulau, Lawrence Bivins. "Sonic Gas Pressure Gauge", Patent # 4869,097 (1989).

[5] Morse, P.M. and H. Feshbach (1953), Methods of Theoretical Physics, McGraw-Hill, New York