JOURNAL OF PROPULSION AND POWER
Vol. 24, No. 1, January–February 2008

Technical Notes

TECHNICAL NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes should not exceed 2500 words (where a figure or table counts as 200 words). Following informal review by the Editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Magnetic Flowmeter Burner Measurement of a Solid Propellant Pressure-Coupled Imaginary Response

Michael M. Micci*
Pennsylvania State University,
University Park, Pennsylvania 16802

DOI: 10.2514/1.29324

I. Introduction

THE pressure-coupled magnetic flowmeter burner, when combined with an acoustic analysis, has been shown to be capable of accurately measuring the real part of a solid propellant pressure-coupled surface combustion response [1]. Magnetic flowmeter burner response measurements for the real part of the response have been compared with response measurements made by the traditional T-burner technique for several composite solid propellant formulations, both aluminized and nonaluminized, with excellent agreement [1–3]. Theoretically, the magnetic flowmeter burner, by measuring the acoustic velocity of the gas above the burning propellant surface, should be able to measure the imaginary part of the pressure-coupled response, something the T burner cannot do. Direct measurements of the in and out of phase components of the acoustic velocity (relative to a forced pressure oscillation) were shown to have the same signal to noise ratios [4]. However, to obtain the most accurate measurement of the pressure-coupled response, the direct measurements of the acoustic velocity as a function of height above the burning propellant surface are combined with an acoustic analysis to determine the pressure-coupled response of the propellant [1]. Whereas accurate values of the real part of the response have been obtained, the same cannot be said for the imaginary part. A value of 10.0 was the maximum real part of the response measured over 97 tests spread among six different propellant formulations over a pressure range from 2.0 to 7.0 MPa, but over the same tests, the measured values of the imaginary part ranged from the unrealistic values of −8.0 to 82.0. Although only the real part of the response is required to perform a stability analysis for a solid rocket motor, the imaginary part is of interest to compute the absolute magnitude of the response and for comparison to other response-measuring devices, such as the ultrasound burner, that are capable of measuring the imaginary part [5,6]. The absence of a scientific understanding of why the magnetic flowmeter burner is unable to accurately measure values of the imaginary part casts doubt on its ability to accurately measure the real part.

Received 15 December 2006; revision received 6 August 2007; accepted for publication 18 August 2007.

*Professor, Department of Aerospace Engineering, 229 Hammond Building. Associate Fellow AIAA.

II. Results

An acoustic analysis is used to calculate the acoustic pressure and velocity as a function of height above a burning propellant surface for a given surface pressure-coupled response [1]. This analysis is matched to measured acoustic pressures and velocities as a function of height above the propellant surface, up to approximately 1.5 cm above the surface, to obtain the surface response. There are two advantages to this method. The use of acoustic velocity measurements provides better resolution than the use of acoustic pressure measurements alone as in the impedance tube method [7]. And the use of acoustic pressure and velocity measurements extending over a distance above the propellant surface has the effect of integrating a number of experimental pressure and velocity measurements to obtain one value for the response.

The solid propellants examined using the magnetic flowmeter burner have heterogeneous compositions and are thus expected to display significant combustion and flow heterogeneity near the burning surface [8]. However, the use of a one-dimensional homogeneous acoustic analysis in conjunction with magnetic flowmeter burner measurements is still considered to be valid for two reasons. First, as stated previously, the magnetic flowmeter burner uses measurements at distances up to approximately 1.5 cm above a propellant surface that has a burning area of approximately 3 cm^2 or more. Surface spatial heterogeneities are on the order of the ammonium perchlorate crystal sizes, which are typically 100 μm or less. The acoustic pressure and velocity measurements are thus an average over a very large number of heterogeneous sites at a distance above the surface where the heterogeneities merge and average together. Second, the purpose of magnetic flowmeter burner measurements is to provide propellant response values for use in solid rocket motor combustion stability prediction codes. These codes assume a constant value for the response for all the propellant contained within the motor and neglect any effects because of propellant heterogeneity.

The magnetic flowmeter burner applies a pressure oscillation to a burning solid propellant surface by modulating the combustion chamber exhaust by rotating a toothed gear over a choked orifice. To eliminate the need for quantitative knowledge of the modulation process, absolute values of the individually measured velocity and pressure oscillations as a function of distance above the propellant burning surface are not used to deduce the response. Instead, the amplitude ratios and phase angles between the velocity and pressure oscillations are used. An examination of the acoustic analysis that is combined with the measured amplitude ratios and phases shows that the real part of the pressure-coupled response influences the phase angle between the velocity and pressure oscillations much more than it influences the amplitude ratio. Figure 1 shows the phase angle between the velocity and pressure oscillations for three values of the pressure-coupled response real part, 1, 3, and 5, whereas Fig. 2 shows the amplitude ratio for values of the real part of 1 and 5. It can be seen that the phase angle is very sensitive to the value of the real part, whereas the amplitude ratio shows almost no sensitivity.

On the other hand, the imaginary part of the pressure-coupled response has almost no effect on the phase angle between the oscillatory velocity and pressure as shown in Fig. 3 for two values of the imaginary part, 1 and 5. The real part of the pressure-coupled response has a value of 1 for both solutions shown. The imaginary part of the response has a small influence on the amplitude ratio

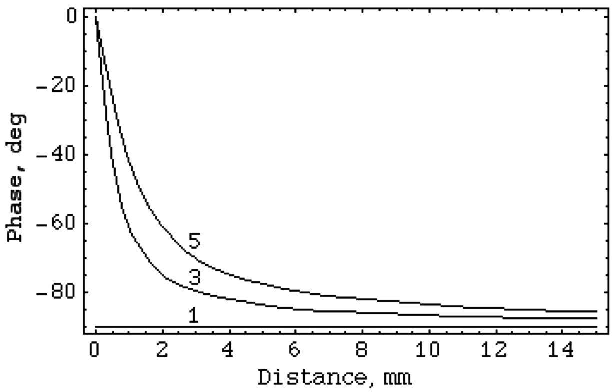

Fig. 1 Phase angle between the oscillatory velocity and pressure as a function of distance from the burning propellant surface for three values of the pressure-coupled real part (one, three, and five).

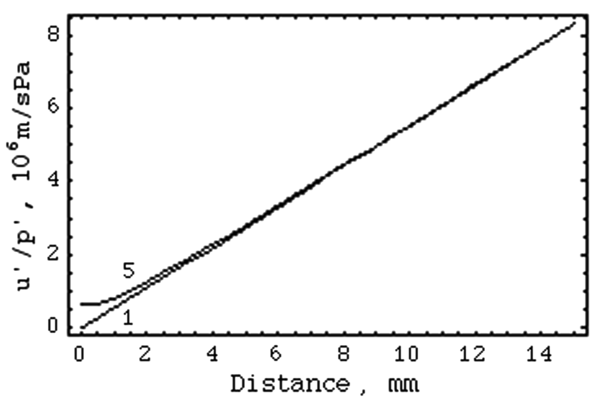

Fig. 2 Amplitude ratio between the oscillatory velocity and pressure as a function of distance from the burning propellant surface for two values of the pressure-coupled real part (one and five).

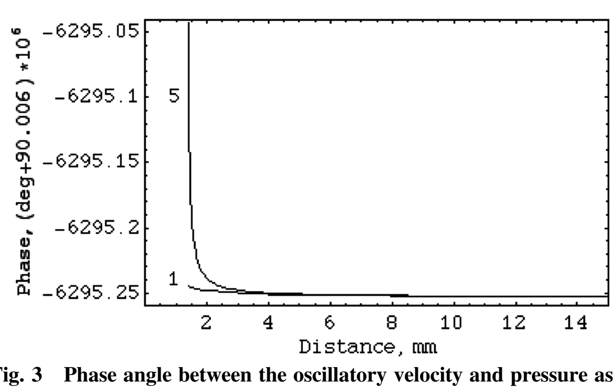

Fig. 3 Phase angle between the oscillatory velocity and pressure as a function of distance from the burning propellant surface for two values of the pressure-coupled imaginary part (one and five).

between the oscillatory velocity and pressure, as shown in Fig. 4. Note that although there is a distinct difference in the amplitude ratios as a function of height above the burning propellant surface, the velocity amplitude must be amplified by a factor of a million to obtain amplitude ratios of the order of one. Also note that at one point above the propellant surface (1 mm), the same amplitude ratio can be given by the two different values of the imaginary part. These two factors make the accurate determination in the magnetic flowmeter burner of the imaginary part of the pressure-coupled response much more difficult than the real part.

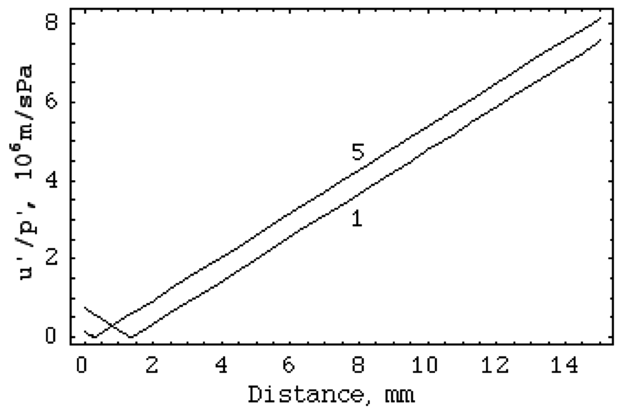

Fig. 4 Amplitude ratio between the oscillatory velocity and pressure as a function of distance from the burning propellant surface for two values of the pressure-coupled imaginary part (one and five).

III. Conclusions

The strong influence of the real part of a solid propellant pressure-coupled response on the phase angle between the oscillatory velocity and pressure of a forced acoustic wave as a function of height above a burning propellant surface permits the accurate determination in the magnetic flowmeter burner of the real part of the response, the parameter that is required to predict the acoustic stability of a solid rocket motor. The weak influence of the imaginary part of the pressure-coupled response on the ratio of oscillatory velocity and pressure amplitudes and the absence of any influence on the more easily measured phase angle between the oscillatory velocity and pressure makes the determination of the imaginary part much more difficult and error prone. This does not, however, detract from the ability of the magnetic flowmeter burner to accurately determine the real part of the response.

References

[1] Cauty, F., Comas, P., Vuillot, F., and Micci, M. M., "Magnetic Flowmeter Measurement of Solid Propellant Pressure-Coupled Responses Using an Acoustic Analysis," *Journal of Propulsion and Power*, Vol. 12, No. 2, 1996, pp. 436–438.

[2] Cardiff, E. H., Pinkham, J. D., and Micci, M. M., "Magnetic Flowmeter Measurement of Pressure-Coupled Response of a Plateau Propellant," *Journal of Propulsion and Power*, Vol. 15, No. 6, 1999, pp. 844–848.

[3] Saretto, S., Herndon, B., Cardiff, E. H., and Micci, M. M., "Pressure-Coupled Response Measurements of Several Aluminized and Non-Aluminized Solid Propellants Using the Magnetic Flowmeter," AIAA Paper 2000-3795, June 2000.

[4] Wilson, J. R., and Micci, M. M., "Direct Measurement of High Frequency Solid Propellant Pressure-Coupled Admittances," *Journal of Propulsion and Power*, Vol. 3, No. 4, 1987, pp. 296–302.

[5] Hafenrichter, T. J., Murphy, J. J., and Krier, H., "Ultrasonic Measurement of the Pressure-Coupled Response Function for Composite Solid Propellants," *Journal of Propulsion and Power*, Vol. 20, No. 1, 2004, pp. 110–119.

[6] Murphy, J. J., and Krier, H., "Evaluation of Ultrasound Technique for Solid-Propellant Burning-Rate Response Measurements," *Journal of Propulsion and Power*, Vol. 18, No. 3, 2002, pp. 641–651.

[7] Baum, J. D., Daniel, B. R., and Zinn, B. T., "Determination of Solid Propellant Admittances by the Impedance Tube Method," *AIAA Journal*, Vol. 19, No. 2, 1981, pp. 214–220.

[8] Massa, L., Jackson, T. L., and Buckmaster, J., "Using Heterogeneous Propellant Burning Simulations as Subgrid Components of Rocket Simulations," *AIAA Journal*, Vol. 42, No. 9, 2004, pp. 1889–1900.

S. Son
Associate Editor