

Development of a GUI Code Based on LabVIEW for the Evaluation of Solid Propellant Burning Rate by Ultrasonic Technique

^[1] Sukanyabai. D ^[2] S. Vasundra

^{[1][2]} Dept of CSE, JNTUA College of Engineering, AP, India

^[1]sukanya.dm857@gmail.com ^[2]vasundras.cse@jntua.ac.in

Abstract: Ultrasonic technique is a latest technique for the measurement of burning rate of solid propellant. PCI based ultrasonic flaw detection card installed in a PC is used to initiate the ultrasonic transducer and store the signals of the reflected pulses in computer memory. This paper discusses the two methods: 1) cross correlation and 2) zero crossing to compute the time lapses from the recorded data. The graphical language LabVIEW utilizing dynamic link libraries developed in C++ is used for developing the entire computation procedure. The software has the advantage of displaying the tracking of the signal and plotting the time lapse against time.

Keywords:—Burning Rate; Solid Propellant; Ultrasonic measurement; Timelapse

I. INTRODUCTION

Solid propellant fuelled propulsive devices generally called Solid Rocket Motors (SRMs) are usually used in booster stage for majority of rockets currently under operation across the world. Characterization of solid propellant in terms of its ballistic parameters [1] (like burning rate, specific impulse, etc.) is very much essential for computing the force generation with respect to time. Several methods [2] are currently available to measure it. Schematic of a solid rocket motor is given in Fig. 1.

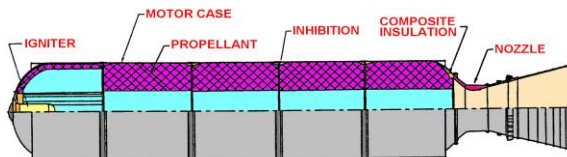


Fig. 1 Schematic of a solid rocket motor

Stand burner [3] and ballistic evaluation motor methods [4] are most commonly used in laboratories as well as propellant manufacturing plants. However, development of advanced techniques such as ultrasonic method, to measure the burning rate more accurately with high reliability is an absolute necessity to cope with the stringent requirements in the flight of rocket.

Ultrasonic Technique

Ultrasonic technique which is non-intrusive, more accurate, has high repeatability, and requires only minimal resources for the measurement of burning rate using propellant specimens is a new method developed within ISRO in recent years [5]. The ultrasonic technique for burning rate measurement [6] is based on the ultrasound principle used for measuring thickness of objects. The thickness (w) of the propellant at the instant of time can be determined from the time lapse (Δt) between the emitted pulse and the reflected echo pulse (Fig. 2) as:

$$w = C \frac{\Delta t}{2} \dots \dots \dots (1)$$

where, C is the velocity of ultrasonic sound in the propellant. The local instantaneous burning rate is calculated as the time-derivative of the propellant thicknesses thus obtained. The propellant burning rate measurement unit is shown in Fig. 3.

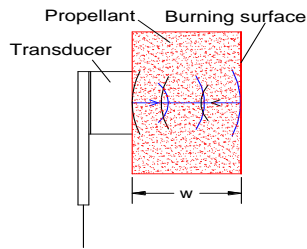


Fig. 2 Principle of ultrasonic technique to Measure burning rate of solid propellant

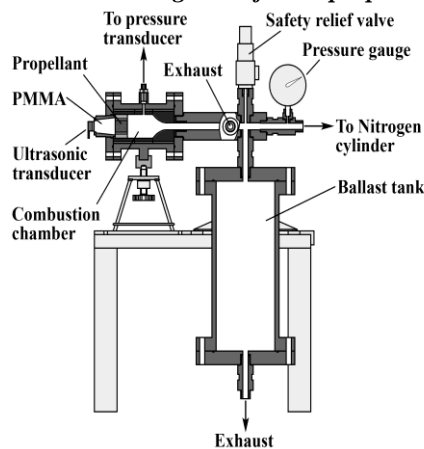


Fig. 3 Test set-up

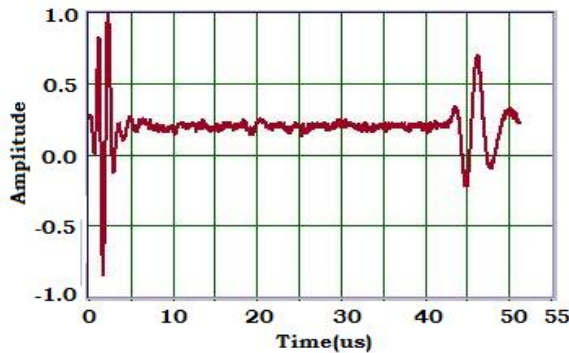


Fig.4 The stored digital signal corresponding to the reflected signals received by a transducer

Digital ultrasonic system acquires these received signals and stored in as digital signals. The signal form in a typical measurement is shown in Fig. 4. The DUS mainly consist of a digital ultrasonic flaw detection card readily available in market, which has two sections: a high voltage section and a data acquisition section. The ultrasonic card used for the present system is SFT-4001PCI, manufactured by Sofratest, France.

The details of the burning rate measurement method can be seen in Ref. [8]. The whole operation of burning rate measurement is controlled through user friendly graphical software. The present study focuses on the development of a graphical code for this second part based on LabVIEW system-design platform and development environment for computers with windows operating system.

Code Development

The reflected ultrasonic signal stored in the computer memory is shown in Fig. 4. The echo signal consists of two high amplitude regions (see Fig. 4). The first region is corresponding to the reflection of ultrasonic wave at the starting end (non-burning-end) of the propellant and the second high amplitude region is corresponding to the burning end (see Fig. 1). Other studies [9] indicates that zero crossing or cross correlation are the best methods for getting time lapse. Both these methods give results with almost equal accuracy. The present study explained the method adopted for getting time lapses using cross correlation and zero crossing techniques.

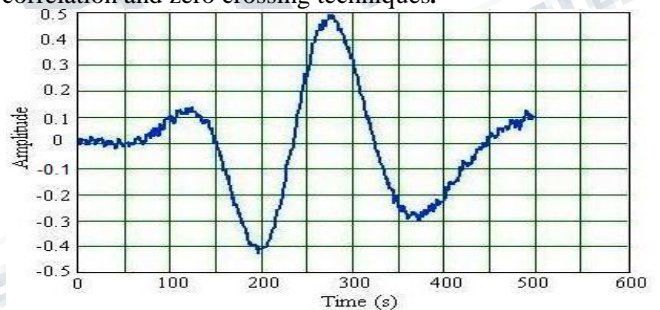


Fig. 6 Enlarged view of the echo signal from the combustion surface.

Cross correlation technique

The cross correlation technique is the comparison of the whole reflected wave with another one to determine the relative position of the second with respect to the first. There can be deformation on the wave as it advances (Fig. 6) but, deformation will be very small between waves at one instant of time and next instant of time. Hence comparison was done to find the reduction in time lapse, Δt such that.

$$\sum [(y_{t_{i+1}} + \Delta t) - y_{t_{i+1}}]^2 = \min \dots \dots \dots (2)$$

However, this method did not work properly because the time-interval between the two consecutive pulses are very small and the value of Δt fell within the dispersion band of t . Hence, the correct advancement of the wave could not be computed. This difficulty was overcome

by skipping a set of in-between waves and compared with a distant wave. But, this procedure reduces the accuracy .

As the direct comparison of two consecutive reflected waves failed, it is planned to correlate the waves to a standard wave and the advancement of the standard wave is computed. The function of the standard wave considered is

$$y = y_{\max} \sin^2[\omega_1(t+a)]\sin[\omega_2(t+a)] \dots\dots\dots(3)$$

This equation is the combination of two waves and it can be further simplified into.

$$y = y_{\max} \frac{\sin\left(\frac{A+B}{2}(t+a)\right) - \frac{1}{2}[\sin(A(t+a)) + \sin(B(t+a))]}{2} \dots\dots\dots(4)$$

Where,

$$A = (\omega_2 + 2\omega_1) \dots\dots\dots(5)$$

And

$$B = (\omega_2 - 2\omega_1) \dots\dots\dots(6)$$

(or)

$$\frac{y}{y_{\max}} = f(t) = \sin \frac{A(1+\varepsilon)(t+a)}{2} - \frac{\sin(A(t+a)) + \sin(A(1+\varepsilon)(t+a))}{2} \dots\dots\dots(7)$$

Where,

$$\varepsilon = \frac{B}{A} \dots\dots\dots(8)$$

In the present technique, it is chosen to fit every wave by least square method to this equation (Eq. 7). This equation contains four constants, such as, y_{max}, A, ε and a. Here, y_{max} determines the maximum amplitude of the wave. The constants are determined by minimizing the error between the point in the reflected wave and curve by Eq. 8. The approximate values of these constants are given in Table 1. Initially and average value is assumed for A, ε and a. Then the constant y_{max} is computed as

$$y_{\max} = \frac{\sum y_i}{\sum f(t_i)} \dots\dots\dots(9)$$

The remaining constants cannot be determined directly and iterative method is to be used. For this, the values of the constants A, and ε, and a are changed with-in the range and the optimum values are found so that the error E in Eq. 10 is mini-mum. Golden ratio method is adopted for the iteration and the value of a is changed first, then ε and finally A and the iteration is continued until reaching

the minimum value for E. The value of a gives the time lapse.

$$E^2 = \left(\frac{y_i}{y_{\max}} - f(t_i) \right)^2 \dots\dots\dots(10)$$

Since the Eq. 7 does not fully represent the shape of the reflected pulse. Hence the portion of the curve covering a portion of the whole first negative peak and a portion of the second positive peak only have considered for fitting which is shown in Fig6.

Table 1

Constants	Approximate values
y _{max}	0.5
A	0.005 – 0.0025
E	0.2 – 0.4
a	0.035

Zero crossing Technique

Zero crossing is the tracking of the first zero crossing value of the wave. The method adopted is fitting a higher order polynomial curve (Fig 8). Through several trails it is found that a fourth order curve is suitable for the fitting.

$$y = a_4t^4 + a_3t^3 + a_2t^2 + a_1t + a_0 \dots\dots\dots(11)$$

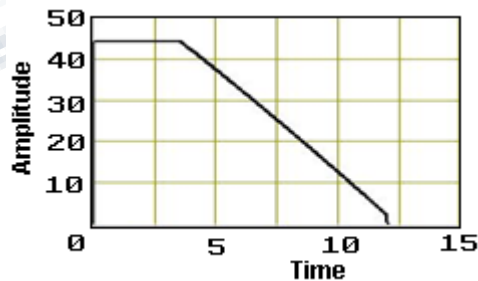


Fig. 8 The portion of the reflected wave considered for the fourth order polynomial fit.

Conclusion and Future work

Both the techniques are found accurate in determining the time lapse but the polynomial fit is found simple, and fast in computation compared to the cross correlation technique. The LabVIEW graphical language incorporating dynamic link libraries developed in C++ is used to display the results in graphical form.

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