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Experimental Installation of Pressure Oscillation based on Pulse-driving Technique

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Abstract : Under the background of combustion instability in solid rocket motor, to study the relationship between pres sure oscillations and dynamic process of propellant flames, it is necessary to simulate an oscillation environment with c ertain frequency, amplitude and duration. This paper presents an experimental installation of pressure oscillation based on pulse-driving technique, with which pressure oscillations features under different pulse-driving conditions were com pared and analyzed. For the pulse-driver applied in this paper, a pressure oscillation with 0.15s-0.5s duration, 179Hz-21 0Hz first order frequency, 0.04MPa-0.35MPa amplitude is simulated. The test results show that an oscillation with high er frequency and lager amplitude can be obtained when pulse-driver is installed on the top of the installation cavity, whi le on the side , an oscillation with a longer duration and an approximate cavity natural frequency can be simulated.

Key Words : Solid rocket motor, Combustion instability, Pulse-driving technique, Pressure oscillation

1. Introduction

Combustion instability is a consistently complicate d and annoying problem for all the SRM (Solid Rock et Motor) designers. Standard Missile, Sidewinder, Harm, Trident, Hellfire and Minuteman just to name a few have experienced pressure oscillations some time during their development and life[1].

As a main and particular feature of combustion in stability, pressure oscillation has profound effect on t he combustion of propellant and then usually leads t o motor failure. Essentially, solid propellant combust ion instability is the amplification or attenuation of ac oustic oscillations by solid propellant combustion pr ocesses in a rocket motor[2].This kind of oscillation has a significant impact on morphology and fluctuati on of propellant flame. The burning processes occur almost entirely within a thin region, normally less th an one millimeter thick, adjacent to the propellant su rface[3]. Pressure oscillation always leads to a burni ng rate increase. Changes in the burning rate cause s further pressure waves, and the cycle is repeated again[4], then motor cavity pressure rises eventually and form a response between combustion process and pressure oscillation.

In order to deeply understand combustion instabili ty and propose reasonable suppression methods, it is necessary to study the dynamic process of propel lant flames under pressure oscillations. This paper p resents an experimental installation which can simul ate pressure oscillations with different frequency, a mplitude and duration.

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2. Experimental Approach

Fig.1 shows the equipment used in our study. Pul se drivers were designed and installed both on the top and side of the installation, a one meter-long cylinder cavity. Pulse driver could produce a high pressure pulse by igniting black powder in the combustor, and the outlet pressures ranged from 20MPa-60MPa according to different powder charge mass. On the bottom side of the main-body, optical windows were designed for observations and image capture of burning surface so that recording the dynamic process of burning flame is available in future.

Fig. 1 Permanent Magnet and Hysteresis Damper Set-up

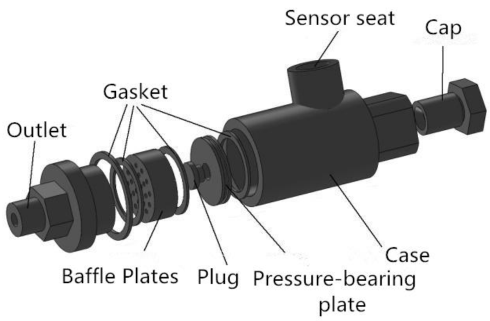


Fig.2 Pulse driver structure Diagram[5]

The cavity was pressurized during the experiments using nitrogen gas. DATALAB Data acquisition system whose maximum sampling rate was 100K for each single channel was applied for experiments. High-frequency response pressure sensors were installed on both ends and middle of cavity, while high-pressure sensor was installed on the pulse driver to measure working pressure in combustor.

According to the previous experience, two pulse drivers I(15g ignition mass)and II(6g ignition mass) were drivers were installed at different positions, both top and side of the cavity. So it was available to compare and analyze the effect of position.

3. Results and Discussions

Five groups of test data under different condition are shown in Table1. Taking the pressure oscillation produced by pulse driver which was installed on the top of main-body and used 15g ignition mass for example, the analysis methods are introduced as below.

Firstly, the pressure oscillation trends in pulse driver combustor and cavity were compared. As shown in Fig.3, the highest pulsing pressure amplitude produced by pulse driver with 15g ignition mass could achieve 50Mpa, pulse duration was about 0.02s, therefore the pressure was obviously changed in the main body and pressure oscillation with a certain frequency and amplitude was produced. Pressure amplitude in main body was obviously lower than the pulse, and lag behind it, but had a longer oscillation time.

Table1. Test data under different conditions

Test	Ignition mass	Installation place	Amplitude (MPa)	Duration (s)
1	15g	Top	0.32	0.16
2	15g	Top	0.30	0.15
3	6g	Top	0.35	0.15
4	6g	Side	0.06	0.50
5	6g	Side	0.04	0.45

On the basis of this, pressure change in the main-body is analyzed before and after pulse driving, as shown in the Fig.4. Before the test, the main body was filled with nitrogen gas at 2.2MPa, which corresponds to the horizontal line at the beginning. When ext ernal pulse was applied, pressure in the cavity rapidly rose to about 3.2MPa and accompanied with intense oscillation, which lasted for a while and fell down slowly, corresponding to the tail part of the pressure curve. The pressure fell down after the oscillation attribute to many factors, such as the temperature decrease with time and the energy loss of pressure wave during the oscillation process.

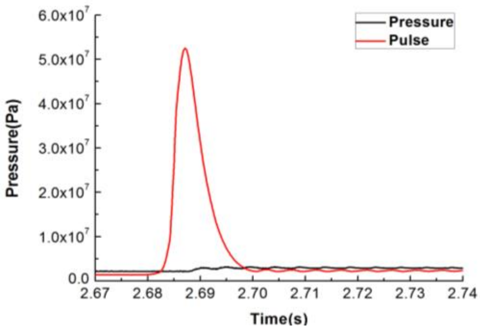


Fig.3 P-t curve of pulse driver combustor and cavity

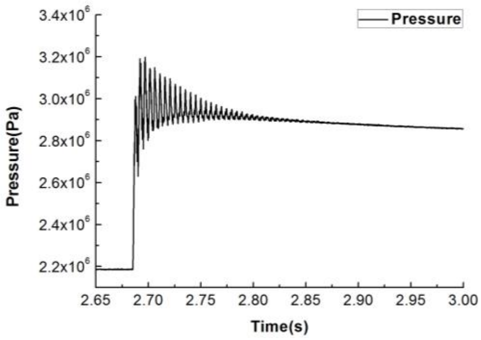
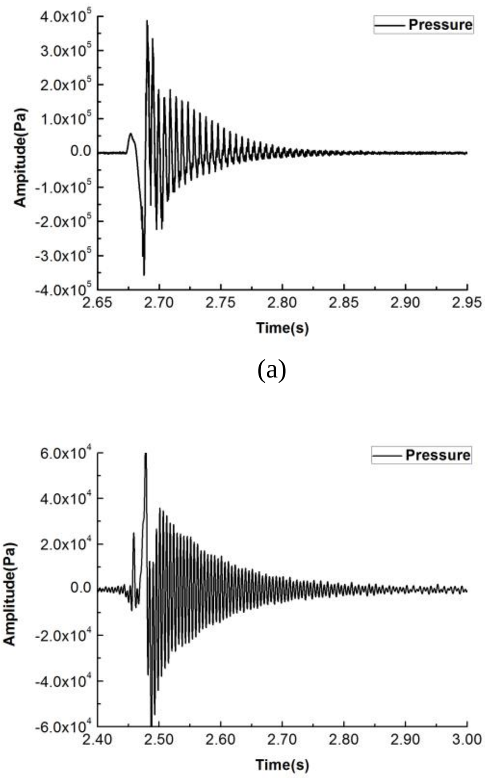


Fig.4 Pressure Oscillation in cavity after pulse driving

Since the pressure oscillation in the pressure curve is of great significance, the oscillation amplitude and frequency needs further study. When pressure curve was smoothed and the equilibrium position is defined, the oscillation characterization can be observed more easily and directly. The maximum amplitude of pressure oscillation was about 0.35MPa, and the oscillation duration was about 0.15s, which was basically in accordance with the linear attenuation trend.

The frequency of oscillation in this area could be obtained by FFT method, first-order frequency was about 209Hz, second-order frequency was about 408Hz. Higher order frequency still existed: third-order frequency was about 608Hz, forth-order frequency was 812Hz, the amplitude of higher order oscillation was smaller than that of low frequency.

In order to compare the effect of pulse driving position, the data of test 3 (ignition mass 6g, installed on the top) and test 4 (ignition mass 6g) is compared as shown in the Fig.5. When the pulse driver was installed on the top of cavity, the pressure could reach 3.2Mpa. While when it was installed on the side position, the pressure change only reached 2.3Mpa. The mean pressure at the former position declines faster than the latter. In the same time interval, pressure at the former position raises from 3.2MPa to 2.6MPa rapidly while the latter maintained around 2.35MPa.



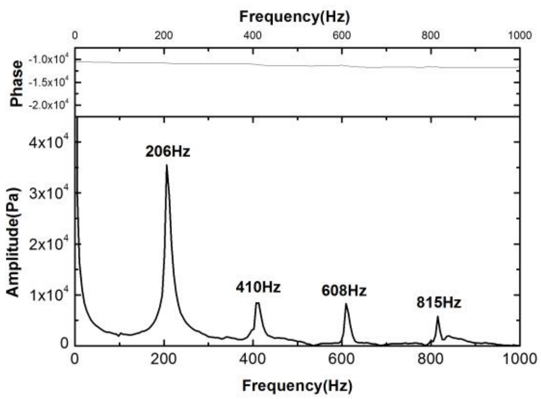
(a)

(b)

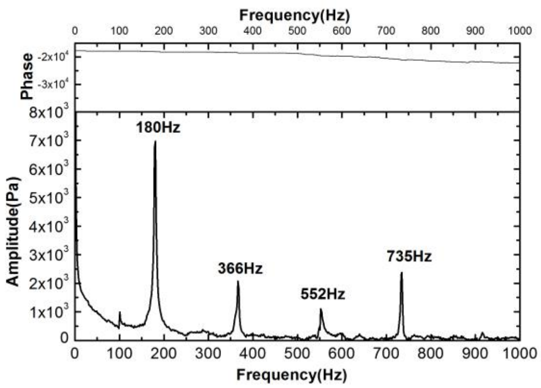
Fig.5 Amplitude and duration of pulse driver were installed on top(a) and side(b) places

Difference of pressure oscillation duration is also shown in the Fig. 5. The pulse driver installed on the top place could produce a 0.15s oscillation while the pulse driver installed on the side place can produce a much longer value of 0.5s. This may because the different installation place led to different travel paths and energy attenuation of pressure wave.

As shown in the Fig.6, pulse driver installed on the top place could produce a pressure oscillation with a 206Hz first-order frequency and a 410Hz second-order frequency; while pulse driver installed on the side place could produce a pressure oscillation with a 180Hz first-order frequency and a 366Hz second-frequency. This may be due to that the pressure wave from top place could travel axially while the pressure wave from side place traveled radially.



(a)



(b)

Fig.6 FFT results of pulse driver were installed on top(a) and side(b) places

4. Conclusions

In this work, five tests under different working conditions were conducted by using an experimental installation, including the frequency, amplitude and duration of oscillation generated by pulse driver in the cavity. For 15g ignition mass, when the pulse driver was placed on the top place, pressure in the cavity was 2MPa and with good sealing, a 2s' oscillation at 200Hz with amplitude of 0.2MPa could be obtained.

For pulse drivers with 6g and 15g ignition mass, the range of the pulse pressure, oscillation duration, first-order frequency generated in cavity, second-order frequency, pressure amplitude were 32MPa-57MPa, 0.15s-0.5s, 179Hz-210Hz, 369Hz-412Hz, 0.04MPa-0.35MPa respectively. The results indicate that a pressure oscillation with higher frequency and amplitude could be obtained when pulse driver is installed on the top place of cavity; while when the driver is installed on the side of cavity, a pressure oscillation can last longer and is much more closed to nature frequency of the cavity.

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