Numerical Simulation of Solid Rocket Motor under Impacting

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Abstract: The solid rocket motor impacting target with a velocity of 200m/s was simulated in this paper. The results show that the motor occurs detonation after the reaction growing in about 25mm. The pressure peak of propellant detonation is about 38.18 GPa.

1. Introduction

During the process of transportation and hoisting of solid rocket motors, accidents such as collisions and falls may occur. In order to increase the energy of the propellant, explosive ingredients such as HMX are added, and it is easy to cause serious accidents such as combustion and explosion. Therefore, scholars have done a lot of research on the process of falling and collision.

Li Jiwei et al. [1] analysed the foreign low vulnerability test standard and criterion, the low vulnerability improvement of solid motor and low vulnerability test. It maybe referenced for designing of the low vulnerability of tactical missile solid motor within our country. Sun Qingmin et al. [2] establish the axial and radial impact models of a two-type high-energy solid rocket motor. The safety analysis and calculation of engine under different speeds and different impact angles were completed. Characteristics of combustion and explosion of solid rocket motor propellant under different impact conditions. Chen Guangnan et al. [3-4] obtained the critical impact velocity for generating high-temperature hot spots by studying the generation of hot spots under impact. Cui Hao et al. [5] determined the parameters of JWL equation of state of detonation product for propellant on the basis of the cylinder test and numerically simulated the falling process of solid motor. Li Guangwu et al. [6] conducted a rocket sled test on a small-sized solid rocket engine and tested its impact detonation threshold and other parameters.

In this paper, the motor radial impact test was simulated numerially using AUTODYN software. ICEM CFD was used to draw high-quality meshes of the engine shell and propellant, and the engine was impacted at a speed of 200m/s by the target.

2. Numerical Simulation

2.1. Numerical Simulation Models

The nonlinear finite element fluid dynamics method (Autodyn17. 0) [7] was used to simulate the process of the motor radial impact test. The engine size is Φ170 mm×150 mm. Figure 1 shows the meshes of engine shell and propellant drawn by ICEM. The shell material is Kevlar, the material state equation is Ortho equation, the strength model is Elastic equation and the erosion criterion is Geometric Strain, and the parameters are taken from AUTODYN standard material library. The equation of state of the propellant is the Lee-Tarver equation. Figure 2 shows the model of the shell engine and the target. Gauge points are set on the side of the propellant near the impact.

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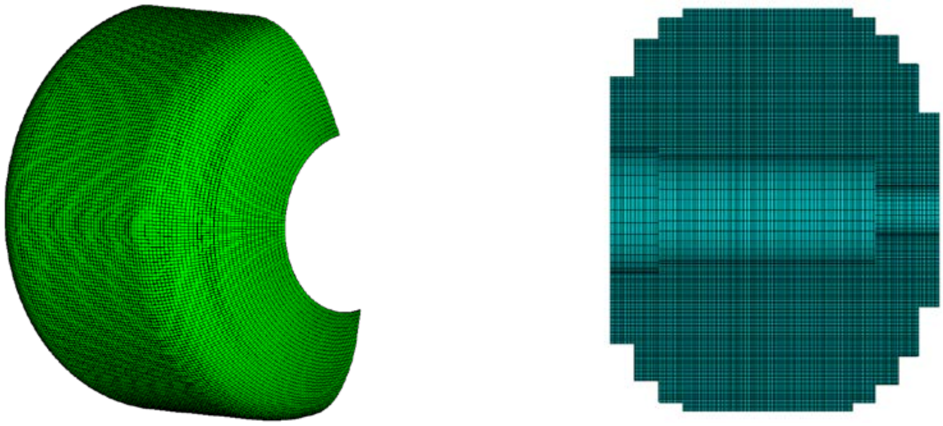

Figure 1 The meshes of engine shell and propellant drawn by ICEM.

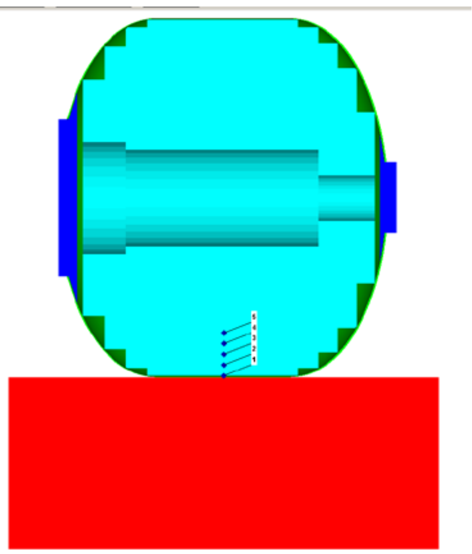

Figure 2 The model of the shell engine and the target.

The propellant is described as Lee-Traver equation, which includes two Jones-Wilkins-Lee (JWL) equations of state and a reaction rate equation [8]. Two JWL equations of state, one of them is for the unreacted explosive and another is for reaction products, in the form:

$$p = A\left(1-\frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1-\frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E_0}{V} \quad (1)$$

where p is pressure in GPas of propellant, V is relative volume, T is temperature of propellant in K, ω is the Gruneisen coefficient, C_v is the average heat capacity, and$A$, B, R_1 and R_2 are constants. The reaction rate equation is:

$$\frac{d\lambda}{dt} = I(1-\lambda)^b\left(\frac{\rho}{\rho_0}-1-a\right)^x + G_1(1-\lambda)^c\lambda^d P^y + G_2(1-\lambda)^e\lambda^g P^z \quad (2)$$

where λ is the ratio of the fraction reacted, F is the fraction reacted of propellant, t is time in μs, ρ is the current density of propellant, ρ_0 is the initial density of propellant, p is pressure in Mbars, and I, G_1, G_2, a, b, c, d, e, g, x, y, and z are constants. The parameters of the Ignition and Growth Modeling showed in Table 1 and 2 [4].

Table 1 JWL equation of state parameters for propellant.

ρ_0/ (g·cm^{-3})	D/ (m·s^{-1})	R_1	R_2	ω	A/ GPa	B/ GPa
1.836	9130.4	5	1.82	0.2	909.59	62.05

Table 2 Parameters of the reaction rate equation for propellant.

I	*b*	*a*	*x*	G_1	*c*	*d*	*y*	G_2	*e*	*g*	*z*
44	0.222	0.01	4	111	0.222	0.667	1.66	200	0.333	0.667	2

2.2. Numerical Simulation Results

The pressure and reaction level of the Gause points in the propellant after impact are shown in Figure 3 and Figure 4. The propellant did not react quickly at the beginning of the impact, but after the impact, the propellant generated hot spots. The pressure of motor at 6.3 μs is shown by Figure 5. As the reaction developed in the propellant, the uncomplete reaction developed to reflection complete. In the curve of reaction level of Gauge#1-#4, it could be seen that the reaction level of Gauge#1-4 did not reach 1.0 before the shock wave propagated to Gauge#5, but in Gauge#5, the reaction developed into a complete detonation. And the propellant at the position of Gauge#1-4 has also been gradually developed to achieve complete detonation. The The pressure of motor at 16.16 μs is shown by Figure 6. The pressure peak of propellant is 38.18GPa, and the distance of detonation developing is about 25mm.

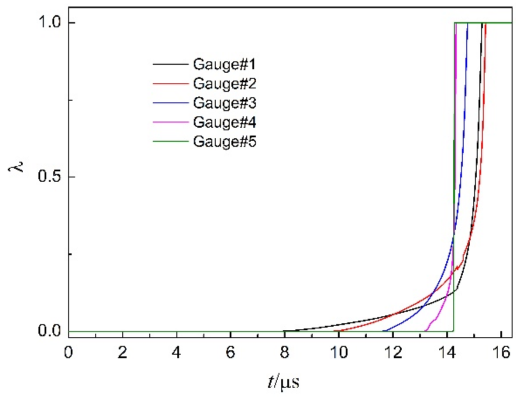

Figure 3 The curves of reaction level of the Gause points in the propellant after impact

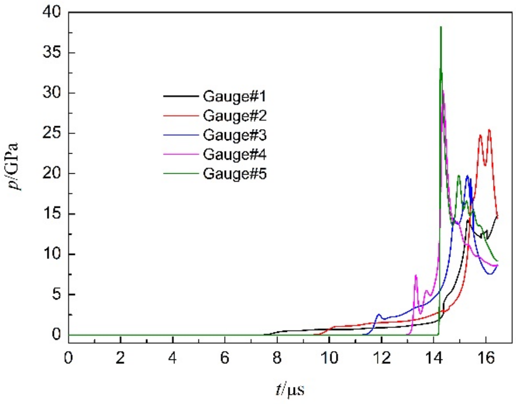

Figure 4 The curves of pressure of the Gause points in the propellant after impact

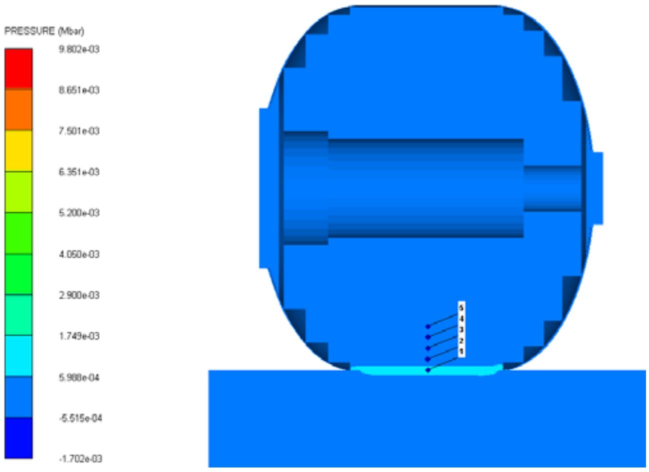

Figure 5 The pressure of motor at 6.3 μs

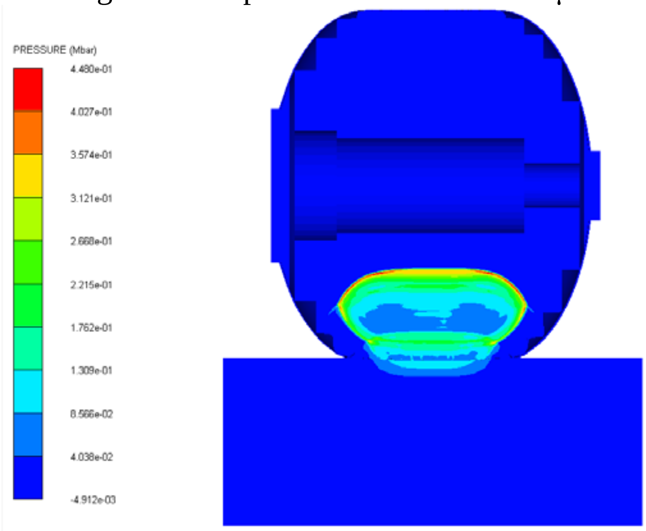

Figure 6 The pressure of motor at 16.16 μs

3. Conclusion

The solid rocket motor impacting target with a velocity of 200m/s was simulated in this paper. The results show that the motor occurs detonation after the reaction growing in about 25mm.The pressure peak of propellant detonation is about 38.18 GPa.

References

[1] LI Jiwei, WANG Junqi，CAO Junwei，ZHANG Zeyuan.The Low Vulnerability Improvement Analysis of Solid Rocket Motor for the Foreign Tactical Missile [J/OL]. Journal of Projectiles, Rockets, Missiles and Guidance: 1-8[2020-06-10]. (in Chinese)

[2] SUN Qingming, WANG Jian. Numerical Analysis of Impact Safety of Solid Rocket Engine [J/OL]. Journal of Solid Rocket Technology :1-7[2020-06-10]. (in Chinese)

[3] CHEN Guangnan, ZHANG Weihua.Numerical Analysis of SRM's Safety under Mechanical Impact[J]. Journal of Aerospace Power, 2006,21(4):784-788. (in Chinese)

[4] CHEN Guangnan.Investigation of the Safety for Solid Rocket Motor under Mechanical Impact[D]. Changsha: National University of Defense Technology,2005. (in Chinese)

[5] CUI Hao, GUO Rui, SONG Pu. Numerical Analysis of Safety of Solid Rocket Engine during Falling Process[J]. Acta Armamentarii, 2018, 39(S1): 66-71. (in Chinese)

[6] LI Guangwu. Research on Impact and Drop Safety of Solid Rocket Engine[D]. Xi'an:

Northwestern Polytechnical University,2005. (in Chinese)

[7] AUTODYN, Explicit Software for Nonlinear Dynamics, Theory Manual, (Century Dynamics) (2005). (in Chinese)

[8] ZHANG Guanren, CHEN Danian. Detonation Kinetics of Condensed Explosive[M]. Beijing: National Defense Industry Press, 1991. (in Chinese)