空气动力学学报
ISSN 0258-1825 CN 51-1192/TK 邮发代号：62-27
ACTA AERODYNAMICA SINICA
主管：中国空气动力研究与发展中心 主办：中国空气动力学会

空气动力学学报 » 2013, Vol. 31 » Issue (05) :657-661 DOI:

二级轻气炮发射过程内弹道数值计算研究

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Numerical research on interior ballistics of the launch process of two-stage light gas gun

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摘要 从二级轻气炮的运行原理出发，发展了内弹道计算程序分析二级轻气炮的操作及其发射性能。建立的数值模型包括：准一维两相流模型用于模拟火药燃烧及其生成气体在火药室和泵管中的流动，准一维可压缩非定常流模型分析氢气在活塞和弹丸之间的流动，一维理想粘塑性模型计算活塞在高压段锥形过渡段中的挤进过程，以及结合经典摩擦定律的摩擦模型计算活塞和弹丸/弹托与炮管之间的运动，气体、活塞/弹托与炮管之间的摩擦和热传导也进行了模拟。采用CFD方法求解流场控制方程，在空间和时间上均具有二阶精度。计算了中国空气动力研究与发展中心的二级轻气炮在典型试验条件下的内弹道特性，并与试验获得的弹丸发射速度进行了对比，计算的弹丸发射速度和试验结果符合较好。发展的二级轻气炮内弹道计算程序还可获得活塞的运动过程，弹丸加速度过载的变化规律，为优化试验装填参数和提高二级轻气炮的发射性能提供理论指导。

关键词： 二级轻气炮 内弹道 超高速发射 两相流 数值模拟

Abstract： Based on the principle of two-stage light gas gun, an interior ballistics numerical analysis program was developed to analyze the performance and operation of two-stage light gas gun. The included numerical models were: a quasi-one-dimensional, two-phase hydrodynamics model to simulate the combustion of solid propellant in the gunpowder chamber and pump tube, an unsteady, quasi-one-dimensional, compressible flow model to analyze the flow of hydrogen gas between the piston and projectile, a one-dimensional, ideal viscoplastic, extrusion model to simulate the motion of piston in high pressure section, and a friction model combined the classical law of frication to describe the motions of piston and sabot in the pump and launch tubes. The friction and heat transfer to the tube wall for gases and solid media are also modeled. The governing equations of gas flow were solved by CFD methods, which have second-order accurate in space and time. The interior ballistics characteristics of two-stage light gas guns of CARDC were analyzed under the typical test operating conditions, and the numerical projectile velocities were agreed well with that of test results. With the help of this program, the motion process of piston and the history of projectile acceleration loads could be obtained. The proposed method provides a way to optimize the operating conditions and improve the performance of two-stage light gas gun.

Keywords： two-stage light gas gun, interior ballistics, hypervelocity launch, two-phase flow, numerical simulation

收稿日期: 2012-04-09;

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引用本文:
黄洁, 梁世昌, 李海燕等 .二级轻气炮发射过程内弹道数值计算研究[J] 空气动力学学报, 2013,V31(05): 657-661

HUANG Jie, LIANG Shi-Chang, LI Hai-Yan etc .Numerical research on interior ballistics of the launch process of two-stage light gas gun[J] ACTA

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