# 基于动网格的空间快速减压过程流场数值模拟与分析 *

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**摘 要**:空间快速减压过程研究及其效应评估和应对防护技术是未来实现临近空间探索、深空探测等重大国家探索工程所必须面临的难题。面向快速减压环境地面模拟装置的研究需求,为了更真实更准确地分析减压过程气体流场特性,预测减压及平衡时间,提出了基于动网格技术的数值模拟方法,完成了特定减压地面模拟装置的仿真分析。结果表明:泄压阀门在尚未完全开启到位时,两舱室的压力已基本持平,弯头在泄压初期平均压力损失较大而后期趋缓。基于动网格技术的分析方法可克服传统方法对泄压阀门开启过程中预测能力不足等问题,可有效获取泄压全周期过程的气体流动特性及压力变化规律。

**关 键 词**:快速减压;动网格;数值模拟;非定常流动

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# Numerical Simulation and Analysis of Spatial Rapid Decompression Process Based on Dynamic Grid

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**Abstract**: The research of rapid decompression process with its effect assessment and protection technology is the problem that must be faced by the future exploration projects such as near space exploration and deep space exploration. In order to analyze the characteristics of gas flow field in decompression process and predict decompression and equilibrium time more realistically and accurately, a numerical simulation method based on dynamic grid technology was proposed to complete the simulation analysis of the ground simulation facility for decompression. The results show that when the relief valve is not fully opened in place, the pressure of the two chambers is basically equal, the average pressure loss of the elbow is large at the initial stage of decompression, but slows down at the later stage. The analysis method based on dynamic grid technology can overcome the problem of insufficient predictive ability of traditional methods in the opening process of relief valve, and can effectively obtain the gas flow characteristics and pressure change law in the full cycle process of decompression.

**Key words**: rapid decompression; dynamic grid; numerical simulation; unsteady flow

空间快速减压是指密封舱在低压环境下突然失密,舱内气压突然下降,伴随气浪冲击、高空缺氧、低温结露等现象。针对空间快速减压过程中气体流动问题,国内外学者进行了大量相关研究[1-10]。Geoffrey 等[11]针对暴露真空的压降过程建立了数值模型并进行了验证研究;Bréard 等[12]对飞机驾驶室可能发生的快速减压过程进行了建模分析;NASA-Marshall 飞行研究中心 Curry 等[13]对空间碎片环境下的国际空间站可能发生的快速减压几率进行建模仿真;北京航空航天大学高海朋等[14]为实现迅速减压,提出了负压储备舱技术,并结合流导方程和气体热力学理论,推导出舱体间气流平衡的数学方程式;贵州大学卢剑锋等[15]通过理论推导和数值模拟等方法完成了 0.01s 迅速减压过程的计算和仿真研究。

快速减压开始时,两舱体内都是低气压气体,舱间压强差并不大,气体的平衡是因为有惯性力存在,所以初始平衡时,气体平衡为湍流形

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