DESIGN AND ANALYSIS OF BLAST VALVE

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by

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Department of Applied Mechanics

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Certificate

This is to certify that the thesis entitled **"Design and Analysis of Blast Valve"** being submitted by **Mr. Pankaj Kumar Sharma** to the Indian Institute of Technology Delhi for the award of degree of Doctor of Philosophy in Applied Mechanics is a record of original, bonafide record of research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard fulfilling the requirements for the degree of Doctor of Philosophy.

The results contained in this thesis have not been submitted in part or in full, to any other university or institute for the award of any degree or diploma.

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Pankaj Kumar Sharma

Abstract

With the advancements in weapon technology, ammunitions have become more precise and lethal. The civil structures required for storage of ammunition and for carrying out special operations have become vulnerable to the blast and shock loads of modern weapon systems. There is a need of innovative and indigenous design of Blast Valve which can fulfil the requirements of ventilation of such structures. The design demands that this device shall be automatic, inexpensive, reliable, reusable, maintenance free, self or remote actuating type and should avoid any leakage of blast pressure. In the present work, an innovative design incorporating best features of remote and self-actuated blast valves is proposed. Since it is a challenge to validate and optimise the design of a valve against blast loads using full-scale experiments, Finite Element Method (FEM) and Computational Fluid Dynamics (CFD) are employed for modelling and simulation of blast valve. The shock-structure interaction analysis of different configurations of the blast valve are performed using ANSYS AUTODYN in order to optimise the design. One of the most important components of the blast valve is circular plate exposed to blast loadings. To understand the effect of blast wave on circular plate and hemispherical shells, the experiments are performed using a shock tube test facility. Plates and shells of different thickness and curvature are subjected to varying blast loads, and strains at different locations are measured in order to optimise the same. The whole exercise in the present research work is carried out to address leakage problem in existing blast valves in order to achieve a design of blast valve with minimum or no leakage.

Based on the detailed simulations, the final blast valve design is obtained. The important features of the final design are: VLC-shaped air flow channel with the outer body materials SS304 and closure mechanism materials DOMEX700MC grade steel, overall length = 750 mm, outer diameter = 420 mm and inlet diameter = 100 mm. The connecting rod is of 10 mm diameter and 614.58 mm long. Hemispherical shell with 96 mm radius of curvature with gradually decreasing thickness from 5 mm at center till 2.5 mm at periphery is used for front and rear closure. The valve is designed for incident pressure of 3 bar and 3.7 ms duration and peak reflected pressure of 7 bar. The air flow rate is 0.14 kg/s under 3000 Pa pressure difference between inlet and outlet.

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सारांश

हथियार प्रौद्योगिकी में प्रगति के साथ, गोला बारूद अधिक सटीक और घातक हो गए हैं। गोला-बारूद के भंडारण और विशेष ऑपरेशन करने वाली आवश्यक नागरिक संरचनाएँ आधुनिक हथियार प्रणाली के विस्फोट और आघात भार के और अधिक चपेट में आ गई हैं। ऐसी स्थिति में ब्लास्ट वाल्व के एक ऐसे अभिनव और स्वदेशी डिजाइन की आवश्यकता है जो ऐसी संरचनाओं के वेंटिलेशन की आवश्यकताओं को पूरा कर सके। इस प्रकार के डिजाइन के लिए यह आवश्यक है कि यह उपकरण स्वचालित, सस्ता, विश्वसनीय, पुन: प्रयोज्य, रखरखाव मुक्त तथा विस्फोट या रिमोट कार्यकारी प्रकार का हो परंतु विस्फोट दबाव के किसी भी रिसाव से मुक्त हो। प्रस्तुत कार्य में, एक अभिनव डिजाइन जिसमें रिमोट और सेल्फ-एक्टेड ब्लास्ट वाल्व की सर्वश्रेष्ठ विशेषताएं शामिल हैं, प्रस्तावित है। चूंकि फुल-स्केल प्रयोगों के माध्यम से इस डिजाइन का सत्यापन और अनुकूलन बहुत चुनौतीपूर्ण है, परिमित तत्व विधि (FEM) और कम्प्यूटेशनल द्रव गतिशीलता (CFD) का उपयोग ब्लास्ट वाल्व के मॉडलिंग और सिमुलेशन के लिए किया गया है। ब्लास्ट वाल्व के विभिन्न विन्यासों के आघात-संरचना परस्पर क्रिया का विश्लेषण ANSYS AUTODYN का उपयोग करके डिजाइन को अनुकूलित करने के लिए किया गया है। ब्लास्ट वाल्व का एक सबसे महत्वपूर्ण घटक ब्लास्ट भारित गोलाकार प्लेट है । गोलाकार प्लेट और गोलार्ध ढांचे पर विस्फोट लहर के प्रभाव को समझने के लिए एक शॉक ट्यूब परीक्षण सुविधा का उपयोग किया गया है। अलग-अलग मोटाई और वक्रता के गोलाकार प्लेट और गोलार्ध ढांचे पर विभिन्न विस्फोट भार के प्रभाओं से उत्तपन्न खिंचाव का मापन विभिन्न स्थानों पर करते

हुए डिज़ाइन का अनुकूलन किया गया है। वर्तमान अनुसंधान कार्य में पूरी कवायद मौजूदा विस्फोट वाल्वों में रिसाव की समस्या को दूर करने के लिए किया गया है ताकि न्यूनतम या बिना रिसाव के साथ ब्लास्ट वाल्व का एक नया डिजाइन प्राप्त किया जा सके।

विस्तृत सिमुलेशन के आधार पर, अंतिम ब्लास्ट वाल्व का डिजाइन प्राप्त किया गया है। अंतिम डिजाइन की मुख्य विशेषताएं हैं: SS304 सामग्री से निर्मित VLC आकार की बाहरी शरीर वाला वायु प्रवाह चैनल और DOMEX700MC ग्रेड स्टील से निर्मित बंद तंत्र सामग्री, समग्र लंबाई = ७५० मिमी, बाहरी व्यास = ४२० मिमी और आंतरिक व्यास = १०० मिमी। कनेक्टिंग रॉड १० मिमी व्यास का और ६१४.५८ मिमी लंबा है। सामने और पिछले द्वारों को बंद करने के लिए ९६ मिमी वक्रता वाले गोलार्ध ढांचे का उपयोग किया गया है जिसकी मोटाई केंद्र में ५ मिमी से धीरे-धीरे घटती हुई २.५ मिमी मोटाई परिधि तक पहुँचती है। ब्लास्ट वाल्व को ३.० बार और ३.७ मिली सेकंड अवधि और ७ बार के शिखर दबाव के लिए डिज़ाइन किया गया है। प्रवेश द्वार और निकास द्वार के बीच ३००० पास्कल के दबाव पर ०.१४ किलोग्राम प्रति सेकंड का प्रवाह दर प्राप्त हुआ है।

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Nomenclature and Abbreviations

Roman Symbols

A : Initial Yield stress in Johnson Cook model

a : Speed of sound

A_S : Projected area

B : Hardening constant in Johnson Cook model

b_r,b_z : Body forces in radial and axial directions

C : Strain rate constant in Johnson Cook model

C_1,C_2,S_1,S_2 : Constants in Shock Equation of State

c_p : Specific heat capacity

d : Displacement of mass element in SDOF model of closure system

D_1,D_2,D_3,D_4 : Damage constants in Johnson Cook failure model

E : Modulus of Elasticity

e : Specific internal energy

E_c : Chemical energy of explosive

f : Dynamic load

F_0 : Maximum amplitude of the load pulse

f_c : Stability factor in CFL criteria

F_{ri},F_{zi} : Components of nodal forces in radial and axial directions

G : Shear Modulus

H : Thickness

I : Moment of inertial about centroidal axis

i, j : Control volume indices

I_S : Specific impulse of ideal blast profile

k : Spring constant

L : Characteristic Length

L_R : Length ratio of model to prototype

m : Mass of closure plate

M_0 : Plastic collapse moment per unit width

m_1 : Thermal Softening Exponent in Johnson Cook model

m_{ii} : Nodal mass of node i

n : Index for updation of field variables in time domain

n_1 : Hardening exponent in Johnson Cook model

n_r,n_z : Unit vectors in the radial and axial directions

n_s : Hardening exponent in Steinberg Gunien equation

P : Pressure

p : Dynamic overpressure

p_c : Static plastic collapse pressure

P_{d1} : Initial Downstream Pressure

P_{d2} : Downstream Pressure Rise

P_g : Static overpressure

P_l : Axial load on connecting rod

P_{shift} : Small initial pressure in JWL Equation of State

R : Radius of curvature

r : Radius

R_0 : Radius of central uniformly loaded region

R_1 : Outer radius of plate

R_S : Radius of the TNT fill

S : Surface area for flux calculation of a cell

T : Temperature

t_a : Arrival time of shock wave

t_c : Valve closing time

t_{d+},t_{d-} : Positive phase and negative phase durations of ideal blast profile

T_{m0} : Melting Temperature

T_{ref} : Reference temperature

U : Velocity of shock

u : Unit step function

u_p : Particle velocity

u_r,u_z : Radial and axial displacements

V : Volume

V_r : Ratio defined by density of the explosive (solid part) and density of the detonation products in JWL EoS

v_r,v_z : Velocities in radial and axial directions

W : Gruneisen coefficient

x,y : Cartesian coordinates

z : Axial coordinate

Greek Symbols

α : Planer angle

β : Plate parameter

β_s : Hardening constant in Steinberg Gunien equation

$\dot{\epsilon}_0$: Reference Strain Rate

$\dot{\epsilon}_p$: Equivalent plastic strain rate

$\epsilon_{\psi\psi}$: Meridional strain

$\epsilon_{\theta\theta}$: Hoop strain

ϵ_f : Dynamic fracture strain

ϵ_p : Equivalent plastic strain

ϵ_{rr} : Normal strain in radial direction

ϵ_{xx} : Normal strain in x-direction

ϵ_{xy} : Shear strain in x-y plane

ϵ_{yy} : Normal strain in y-direction

ϵ_{zr} : Shear strain in z-r plane

ϵ_{zz} : Normal strain in axial (z) direction

$\epsilon_{pl,i}$: Initial equivalent plastic strain

ν : Poission's Ratio

ν_r : Relative volume

ω : Frequency of oscillations

π : Dimensionless parameter

ρ : Mass Density

σ_0 : Minimum yield strength

$\sigma_{\theta\theta}$: Hoop stress

σ_{ac} : Permissible stress in connecting rod

σ_{rr} : Normal stress in radial direction

σ_v : von-Mises stress

σ_Y : Yield stress

σ_{zr} : Shear stress in z-r plane

σ_{zz} : Normal stress in axial (z) direction

θ : Circumferential coordinate

$\dot{\epsilon}^{p}{}_{\theta\theta}$: Equivalent plastic hoop strain rate

$\dot{\epsilon}^{p}{}_{rr}$: Equivalent plastic normal strain rate in radial direction

$\dot{\epsilon}^{p}{}_{zz}$: Equivalent plastic normal strain rate in axial direction

$\dot{\gamma}^{p}{}_{rz}$: Equivalent plastic shear strain rate in r-z plane

Abbreviations

CFD : Computational Fluid Dynamics

$CFEES$: Centre for Fire, Explosive and Environment Safety

CFL : Courant-Friedrichs-Lewy

$DOMEX$: High-strength steel of the Swedish firm SSAB

EoS : Equation of State

FCT : Flux-Corrected Transport

FEM : Finite Element Method

FSI : Fluid Structure Interaction

ISO : International Standards Organization

JC : Johnson cook model

JWL : Jones-Wilkins-Lee

$PE4$: Plastic Explosive No. 4

$QUICK$: Quadratic Upstream Interpolation for Convective Kinematics

$SDOF$: Single Degree of Freedom

$SHASTA$: Sharp And Smooth Transport Algorithm

$SIMPLE$: Semi-Implicit Method for Pressure Linked Equations

$SS316$: Stainless Steel grade 316

TNT : Trinitrotoluene