

Pyrotechnic Modeling **N 9 3 - 2 0 1 5 3**

for the NSI and Pin Puller

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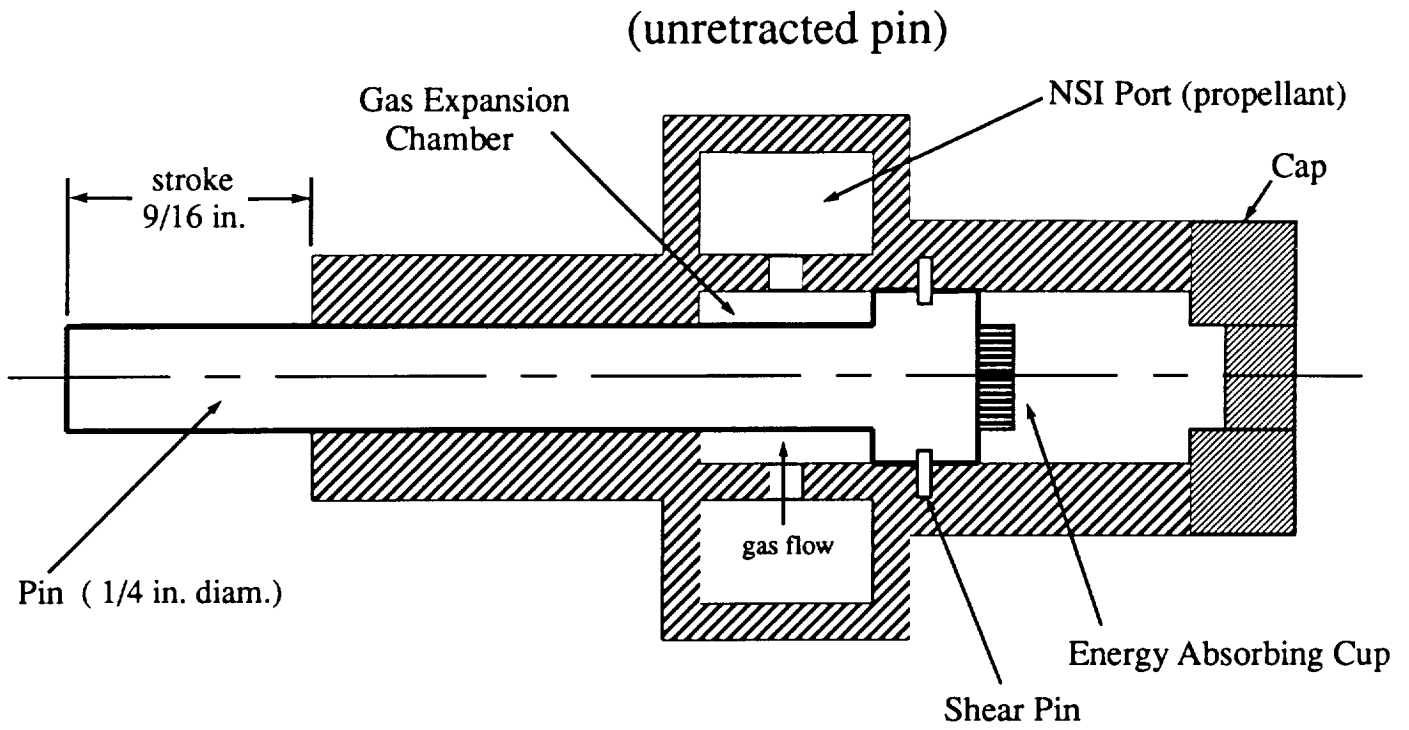
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Discussions

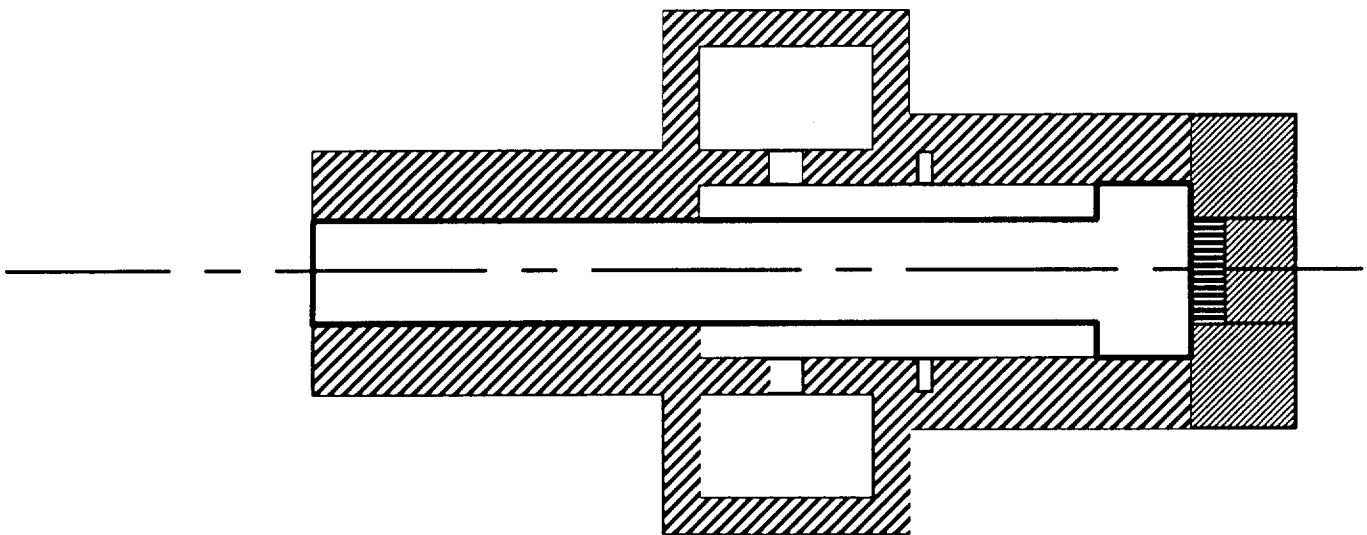
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NSI Driven Pin Puller



(retracted pin)



Review

Sources for guidance in model development:

- Pin-puller tests: Bement, Schimmel, et al.
- Pyrotechnics chemistry: McLain, Conklin
- NSI ignition study: Varghese
- Multiphase combustion: Baer, Nunziato, Krier, Powers, etc.
- Automobile airbags: Butler
- Solid propellants: Williams, Kuo, Strehlow, etc.
- Solid state combustion synthesis: Varma

Engineering Problems

- occurrence of operational failures
- qualification only after many tests
- difficult to predict behavior of new formulations
- difficult to quantify effects of modifications
 - diffusive heat transfer
 - molecular heat transfer
 - pin puller geometry
 - friction
 - apparantly random sample behavior

Modeling Approaches

- Full Scale Models
 - time-dependent
 - three-dimensional spatial gradients
 - multiple species, multiple reactions
 - fully resolved chemical kinetics
 - compressibility
 - turbulence
 - real gas effects
 - boundary layers
 - *essentially no detailed kinetic data available*
 - *more complex than justified by data*

- Empirical Models
 - experimentally-based correlations
 - reliable in limited ranges
 - somewhat inflexible
- Simple Models-*present approach*
 - analytically tractable
 - judgment required
 - simplicity at expense of loss of rigor
 - introduction of ad hoc assumptions
- Stochastic Models
 - estimates for uncertainty required
 - could be coupled with simple model

Assumptions for Simple Model

- no spatial variation

$$- t_{acoustic} \sim \frac{L}{c} \sim \frac{0.01m}{1000m/s} = 1 \times 10^{-5}s$$

- constant density solid pyrotechnic
- constant surface area of pyrotechnic
- linear pyrotechnic burn rate known
- constant temperature wall
- simple convective heat transfer

$$- t_{conv} \ll t_{cond} \sim \frac{L^2}{\alpha} \sim \frac{(0.01m)^2}{0.001m^2/s} = 0.1s$$

- simple radiative heat transfer

$$- t_{rad} \sim \frac{\rho_g c_{vg} L}{\sigma T^3} \sim \frac{1kg/m^3 1000J/(kgK) 0.01m}{1 \times 10^{-7} J/(sm^2 K^4) (1000K)^3} = 0.1s$$

- negligible heat transfer from gas to solid
- negligible wall friction and shear pin resistance
- non-negligible pin inertia
- multicomponent ideal gas behavior
- temperature dependent specific heat
- Gibbs free energy minimization
 - determines heat of reaction
 - determines mass fractions of gas products

Conservation Principles

for background see

Powers, Stewart, and Krier, "Theory of Two-Phase Detonation—Part I: Modeling, Part II: Structure,"

Combustion and Flame, V. 80, 1990.

$$\frac{d}{dt} [\rho_g V_g] = \rho_s A r$$

$$\frac{d}{dt} [\rho_s V_s] = -\rho_s A r$$

$$\begin{aligned} \frac{d}{dt} [\rho_g V_g e_g] &= \rho_s A r e_s + h A (T_w - T_g) \\ &\quad + \sigma A (\alpha T_w^4 - \epsilon T_g^4) - P_g \frac{dV}{dt} \end{aligned}$$

$$\frac{d}{dt} [\rho_s V_s e_s] = -\rho_s A r e_s$$

$$m_p \frac{d^2}{dt^2} \left[\frac{V}{A} \right] = P_g A$$

Constitutive Relations

$$r = a + bP_g^n$$

$$P_g = \rho_g RT_g \sum_{i=1}^{N_g} \frac{Y_i}{M_i}$$

$$e_g = \sum_{i=1}^{N_g} Y_i \left(h_{fi}^o + \int_{T^o}^{T_g} c_{pi}(\hat{T}_g) d\hat{T}_g \right) - RT_g \sum_{i=1}^{N_g} \frac{Y_i}{M_i}$$

$$e_s = \sum_{i=1}^{N_s} Y_i \left(h_{fi}^o + \int_{T^o}^{T_s} c_{pi}(\hat{T}_s) d\hat{T}_s \right)$$

$$V = V_g + V_s$$

Y_i estimated from minimization of Gibbs free energy

Variables

$$e_g, V_g, T_g, P_g, \rho_g,$$

$$e_s, V_s, T_s,$$

$$V, Y_i, r$$

Constants

$$\rho_s, A, h, T_w, \sigma, \alpha, \epsilon, m_p, a, b, n, R, M_i$$

Piston Energy calculation

Knowledge of $P_g(t)$ and $V(t)$ allows calculation of work done by pyrotechnic material:

$$W(t) = \int_0^t P_g(\hat{t}) \frac{dV(\hat{t})}{d\hat{t}} d\hat{t}$$

Current Solution Approach

- use NASA Lewis CEC code to estimate equilibrium products via minimization of Gibbs free energy
- solve coupled ODE–algebraic system
 - numerical integration of ODE
 - SLNL-CHEMKIN package to determine gas energy
- calculate work done by gas
- compare peak pressure and work with observations

Future

- wall friction
- shear pin effects
- spatial resolution
- grain size effects
- burn rate experiments
- detailed chemistry
- stochastic effects

Conclusions

- literature search shows little published articles on modeling of pyrotechnically driven actuators
- insufficient constitutive data for full-scale model
- simple deterministic model appears useful to better guide design
- assumptions of simple model preclude capturing of many observed phenomena
- results from simple model should be first evaluated then decisions made regarding where to make improvements

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APPENDIX B - Written Questions and Answers

Question:

Response:

Dr. Lien C. Yang (TRW)

Absorptive particulated doped HMX and PETN can be initiated by laser. But the threshold may degrade post environmental test, especially temperature cycling. Are there plans to perform any test?

Dr. J. A. Merson (Sandia Nat. Labs)

Yes. Powder separation may be a problem. It is no different than bridgewire decoupling and therefore there are engineering solutions.

Dr. Richard Craig (Spectra Diode Labs)

As you develop a standard laser diode safe and arm:

- 1) How do you get input from system and component manufacturers?
- 2) How will you distribute your concepts to the community?

Mr. Barry Wittschen (NASA/JSC)

1) The word "standard", as applied to a laser safe and arm may be a misnomer. What we are going to attempt to do is identify major criteria for system configuration, methods for implementing inhibits, methods for qualifying the S&A and acceptance test requirements.

2) The most critical application for the S&A is in flight termination systems (FTS). FTS requirements are established by the range safety organizations. The primary input will therefore develop through dialogue with the ranges and then be distributed by the ranges in the form of revisions to their own safety requirements. Additional distribution will be through future NASA and AIAA conferences.

Dr. Lien C. Yang (TRW)

Is it possible to re-adopt ASI (Apollo Standard Initiator) output charge design using $\text{TiH}_2/\text{KeLO}_4$ composition for increasing the gaseous output? ASI was extensively tested in 1960's. Large performance data base exists.

Mr. Larry Bement (NASA/LaRC)

No possibility exists to change the output charge in the NSI, as it is now qualified. The $\text{TiH}_2/\text{KeLO}_4$ may be some benefit for the NASA Standard Gas Generator, but the ignition and primary charge must remain Zr/KeLO_4 .

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