2020 ICDT

INTERNATIONAL CONFERENCE ON DEFENCE TECHNOLOGY

26th - 29th October 2020 | Online Event

Development of the analytic relations for the propellant grain geometrical characteristics required for a maximum pressure plateau feature

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Fundamental relations used in the interior ballistic calculus

- The interior ballistic fundamental equation
  $$pW = f\omega\psi - \frac{(\gamma-1)\varphi q v^2}{2} \qquad W = W_0 - \frac{\omega}{\delta}(1-\psi) - \alpha\omega\psi + sl$$
- The burning rate law
  $$u = Ap^{\nu} \qquad \psi = \frac{\omega_{ars}}{\omega} \qquad z = \frac{e}{e_1}$$
- The propellant gases rate generation law
  $$\psi = \chi z(1 + \lambda z + \mu z^2) \qquad \sigma = 1 + 2\lambda z + 3\mu z^2$$
- The influence of grain geometry on the gases rate generation
  $$\frac{d\psi}{dt} = \frac{S_0}{\Lambda_0}\frac{S}{S_0}Ap^{\nu} \qquad \frac{S_0}{\Lambda_0}e_1 = \chi$$
- The projectile translation equation
  $$sp = \varphi q\frac{dv}{dt} \qquad \varphi = 1.04 + \frac{1}{3}\frac{\omega}{q}$$

Deduction of the geometrical characteristics required for a constant pressure plateau

The constant pressure plateau implies:

- a null time derivative for the pressure,
  $$\frac{v}{\sigma} = \frac{\omega\frac{S_0}{\Lambda_0}Ap_{max}^{\nu}}{s(1+\theta)p_{max}}\left[f + p_{max}\left(\alpha - \frac{1}{\delta}\right)\right] = cst. \longrightarrow \frac{v_{p_{max}}}{1 + 2\lambda_c z_{p_{max}} + 3\mu_c z_{p_{max}}^2} = \frac{v_k}{1 + 2\lambda_c + 3\mu_c}$$
- a linear evolution of velocity in time,
  $$v_k = v_{p_{max}} + \frac{sp_{max}}{\varphi q}\Delta t$$
- and a constant burning rate.
  $$e_1\left(1 - z_{p_{max}}\right) = \Delta t A p_{max}^{\nu}$$

$$\chi_c = 1 - \frac{\gamma}{2\varphi q}\frac{e_1^2}{\omega}\left(\frac{sp_{max}{}^{1-\nu}}{A}\right)^2\left[f + p_{max}\left(\alpha - \frac{1}{\delta}\right)\right]^{-1}$$

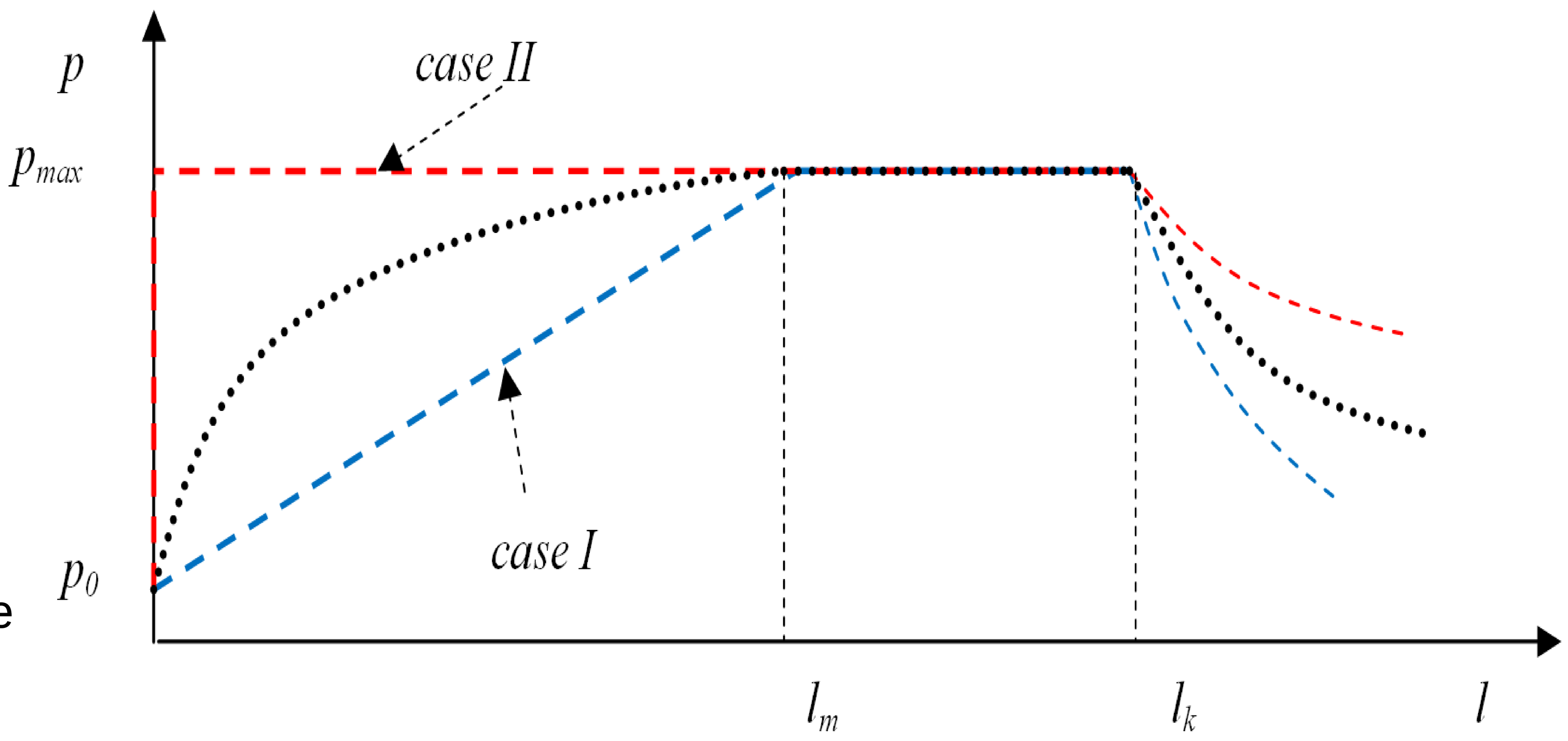
$$\lambda_c = \frac{\frac{\gamma}{2\varphi q}\frac{e_1^2}{\omega}\left(\frac{sp_{max}{}^{1-\nu}}{A}\right)^2\left[f + p_{max}\left(\alpha - \frac{1}{\delta}\right)\right]^{-1}}{1 - \frac{\gamma}{2\varphi q}\frac{e_1^2}{\omega}\left(\frac{sp_{max}{}^{1-\nu}}{A}\right)^2\left[f + p_{max}\left(\alpha - \frac{1}{\delta}\right)\right]^{-1}}$$

$$\mu_c = 0$$

Case study for an realistic gun

Table 1. Gun, projectile and propellant characteristics

Gun/projectile characteristics				Propellant characteristics				
W_0 [m³]	s [m²]	φq [kg]	p_0 [Pa]	δ [kg/m³]	f [J/kg]	α [m³/kg]	A [m/s/Pa$^{\nu}$]	ν [N/A]
$1.391\cdot10^{-3}$	$4.35\cdot10^{-3}$	6.677	$5*10^7$	1650	935000	10^{-3}	$1.1\cdot10^{-7}$	0.724



Extreme Case I - the minimum values are given when the pressure increases in a linear manner

Extreme Case II - the maximum values are given when the pressure suffers a sudden increase from right at the beginning of the movement and then remain constant

For the analysed gun system, **there is not possible to reach a constant pressure plateau** when is used a propellant characterised by a single set of geometrical characteristics over the entire web thickness

Conclusions

Analytic functions for the geometrical characteristics required for a constant pressure plateau were deduced

There is not possible to reach a constant pressure plateau when in a realistic gun system with a propellant charge characterised by **a single set of geometrical characteristics** over the entire web thickness

A start point in the development of some similar formulas and methods that deal with more complicated grains geometries as such those obtained through co-extrusion or 3D printing, for which the constant maximum pressure plateau is feasible