Model Based Design of Pressure Profiles for Pyrotechnic Actuator Using SPH Method & LsOpt© Solution

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Abstrcat. *The design of Pyrotechnic Pistons is subjected to many unknowns, its methodology sometimes consists of many experiments in a trial & error process.*
This paper presents the design process of such a device. In this work a model–based design process was applied using LsDyna© model and LsOpt© optimized solution obtaining upper and lower bounds for the pressure profiles of a pyrotechnic piston device. The numerical solution decreases the number of required experiments in the design process and cuts its costs.

1 Introduction

1.1 Background

Pyrotechnic Pistons are commonly used as fast reacting actuators in many fields and applications, such as seat belt pretensioners, wire and cable cutters and power disconnect devices. The common design of such devices consists of a pyrotechnic component which actuates the movement of a mechanical assembly that performs the device's main purpose. The design of the pyrotechnic component should provide the mechanical device enough energy to perform its goal.
The mechanical requirements for these devices defines the pyrotechnic requirements, but the translation of these requirements can, sometimes, be quite complicated, since it dependents on the dynamic behavior of the device and the materials it is made of. Defining the pressure profiles and bounds required for these pyrotechnic components can decrease the amount of pyrotechnic experiments during the design process which is done many times in a trial & error methodology. The main goal of this work is to define these bounds, for a specific device.

1.2 The pyrotechnic micro wire cutter

This paper will present a Model Based Design (MBD) process of a micro wire cutter. This device uses the energy of a pyrotechnic component to accelerate a steel piston. This piston hits a locker which holds a 1.2$_{mm}$ aluminum wire.
Figure 2 presents the components of this micro wire cutter:

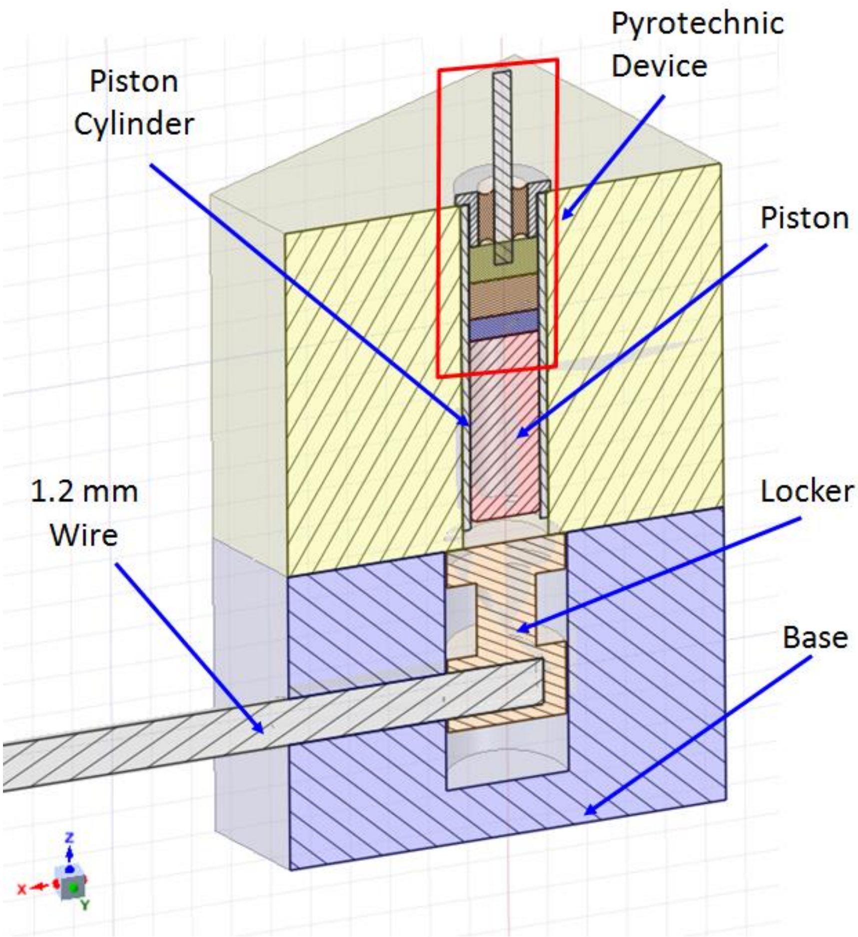

Fig.1: The pyrotechnic micro wire cutter

As seen in Fig.1: the pressure produced by the activation of the pyrotechnic component pushes the piston towards the locker, once it hits it, the locker shears the aluminum wire. If the pressure will be high enough, the stopper will cut the wire and hit the device base.
The requirements of this device are to cut the wire at a *maximum time of* $500_{\mu Sec}$ with 0.1_{mm} *maximal deflection of the device base.*
The goal of this work is to determine two pressure profiles that will act as lower and upper bounds for the pyrotechnic component design process.

1.3 The pyrotechnic design process

The common design process in the pyrotechnic department consists of many experiments in a trial & error methodology. The pressure profiles of these components are determined in "Closed Volume" ignition experiments which do not necessarily represent the real environment of the operational system. Fig.2: presents a typical pressure profile of a pyrotechnic component which is determined in a "Closed Volume" experiment:

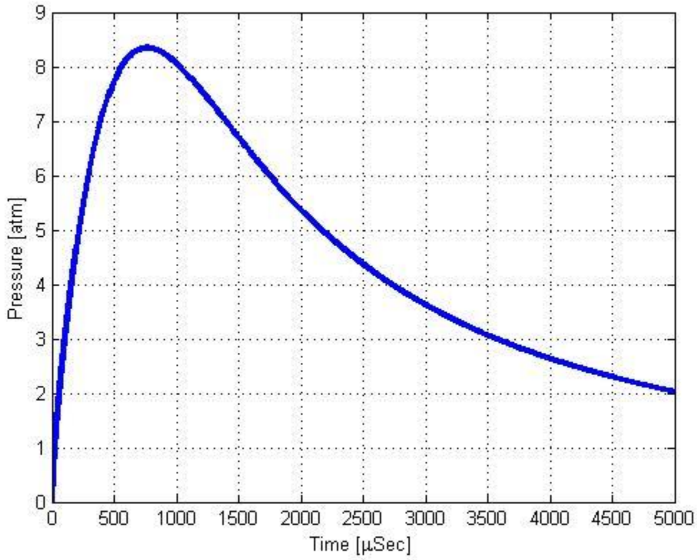

Fig.2: A typical pyrotechnic pressure profile

In order to learn about the mechanical behavior of the actual operational system, a full trial is required. These experiments can be very complicated, are sometimes destructive and require the manufacturing of many prototypes. Furthermore, this methodology requires detailed mechanical design and can't be done in early stages of the design. The use of a pre numerical simulation is therefore invited.

2 The Numerical Model

A Finite Element model representing the wire cutter and the piston was built. Assuming symmetry, the model was built as a half body with relevant symmetry conditions. The pyrotechnic pressure was modeled using a pressure load acting directly on the relevant surfaces.

2.1 Components and Materials

The FE model can be seen in Fig.3:

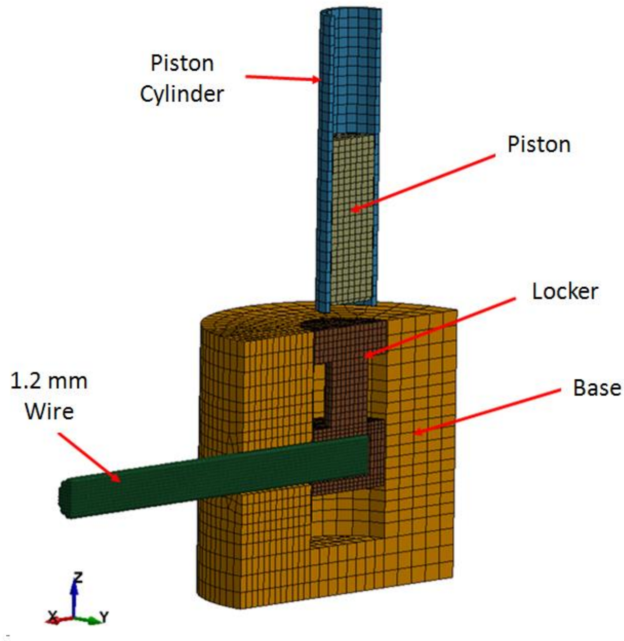

Fig.3: The FE model

The components which are included in the model:

- Locker & wire base
- Piston's cylinder
- Wire
- Piston
- Locker

The wire was modeled using SPH particles mostly due to better contact behavior around the cutting edges of the base and the locker. The rest of the model was modeled as fully integrated Lagrange elements.
All the materials in the model have elasto-plastic properties modeled using **`*MAT_PIECEWISE_LINEAR_PLASTICITY_(024)`**, the locker and the wire consider failure in their material model.

Table 1: The numerical model properties

# of nodes	14893
# of solid elements	7670
# of SPH nodes	5625
# of parts	5
# of material models	4
# of contact definitions	5
Maximum solution time on 8 core machine	25 minutes

Table 1: shows information about the numerical model. It can be seen that the short solution time of this model makes it suitable for optimization tasks which contain many LsDyna© executes.

2.2 Loads and Boundary Conditions

The piston cylinder and the base are fixed using a 6 DOF nodal constrained boundary condition. A pressure load is applied on the piston, Fig.4: shows these boundary conditions. This load is a time and displacement dependent pressure as described in the following equation:

$$P = \frac{V_0}{V(t)} \cdot \frac{a \cdot t^n}{1 + t^2} \tag{1}$$

Where:

- $V(t) = V_0 + A \cdot dz$
- P- The applied pressure [Pressure units]
- t- Physical time [mSec]
- a- Pressure coefficient [Pressure units]
- n- Time decay coefficient
- V_0- The initial volume of the pyrotechnic device [mm^3]
- A- The piston's cylinder cross section area [mm^2]
- dz- The displacement of the piston [mm]

This equation contains two parts- the volume fracture which assumes adiabatic behavior for the pyrotechnic device, and the closed volume pressure profile (the second fracture in the equation).

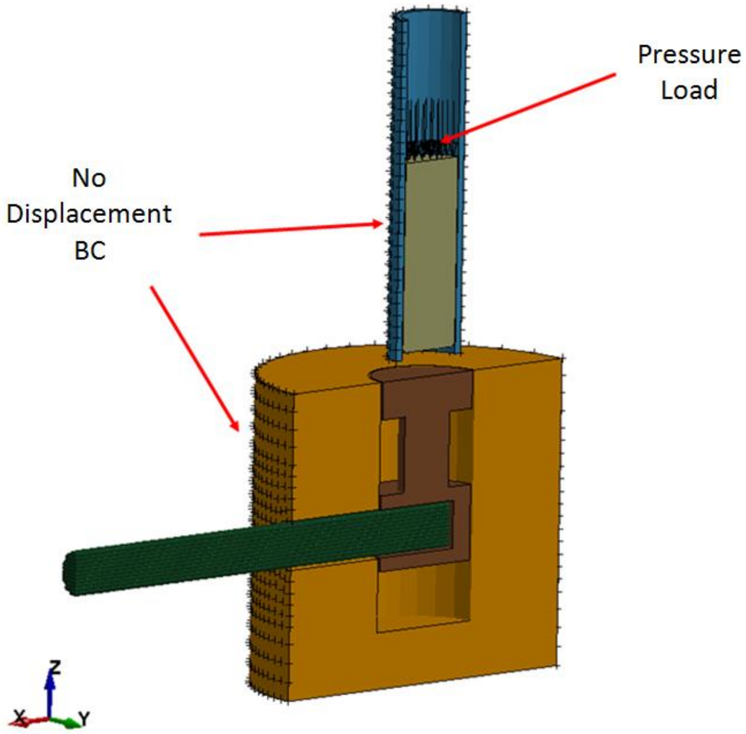

Fig.4: The model's BC's

Equation 1 was implemented in the model using **`*DEFINE_CURVE_FUNCTION`**. The parameters "a" and "n" define the pyrotechnic device behavior and were later defined as the optimization variables.

3 The Optimization Tasks

As mentioned before, the main goal of this work was to define lower and upper bounds for the pyrotechnic device's pressure profiles in order to decrease the amount of experiments during the design process. In order to do so, two different optimization tasks were built in LsOpt©, one for each boundary profile. The design task had two constraints:

- Cutting the wire before reaching $500_{\mu Sec}$
- 0.1_{mm} maximal deflection in the device's base

The design variables in both tasks were the "a" and "n" parameters shown in Equation 1.
The upper boundary profile task's objective was to *maximize* the piston's velocity with the constraint of 0.1_{mm} maximal deflection in the device base.
The lower boundary profile task's objective was to *minimize* the piston's velocity with the constraint of maximum cutting time of $500_{\mu Sec}$.
In both tasks use metamodel- based optimization method with RBF metamodel type and Space Filling sampling algorithm were used.

4 Results

The failure of the wire still needs to be calibrated by carrying out experiments. This is planned to be done later this year.

Table 2: shows the results of both optimization tasks:

Table 2: The optimization tasks results

	$t(P_{max})$ [µSec]	P_{max} [atm]	n	a [atm]
Upper Boundary Task	128	11.6	0.081	22.9
Lower Boundary Task	577	4.8	0.737	16.1

The results determine a range of peak pressures found from the optimization procedure. On the one hand the wire is cut before reaching 500 µSec (lower boundary). On the other hand the deflection of the base is less than the maximum allowed (upper boundary). The optimization procedure takes into account the change of pressure acting on the piston due to the change in volume in the cylinder during the movement of the piston as presented in equation 1.
These results will be used by the pyrotechnic design team for testing their results in a "Closed Volume" experiment. Thus, the pressures found in the simulation should be translated into a "Close Volume" (or constant volume) profile, this will be done by placing $V(t)=V_0$ in Equation 1(parameters "n" and "a" are as found in the simulations). This will lead to the pressure profiles presented in Fig.5:

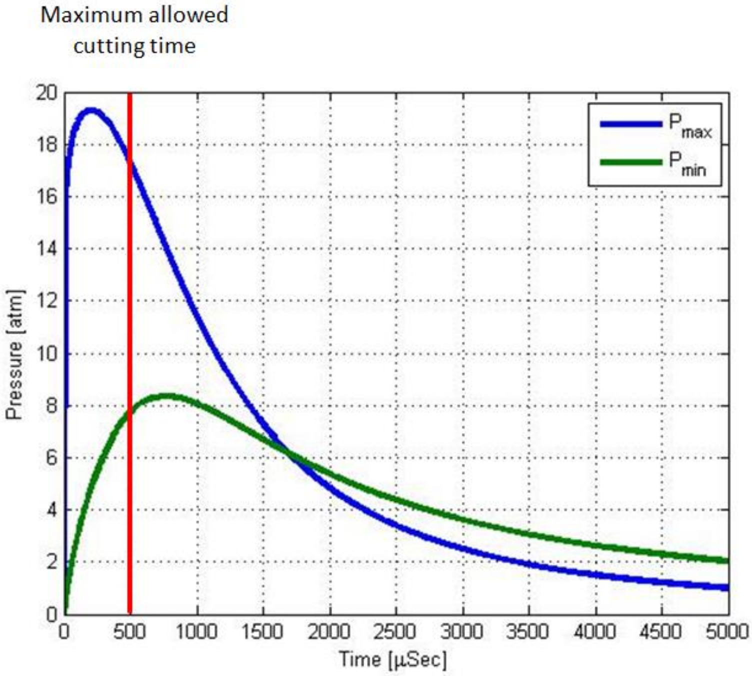

Fig.5: The lower and upper bounds for the pyrotechnic component design

The red line in Fig.5: represents the time constraint for the wire cutting action (maximum 500 µSec). It can be seen that although the lower bound profile (in green) has not reached its peak pressure, it was able to cut the wire.
Fig.6: presents a closer look on the pressure bounds in the 0÷500 µSec time frame:

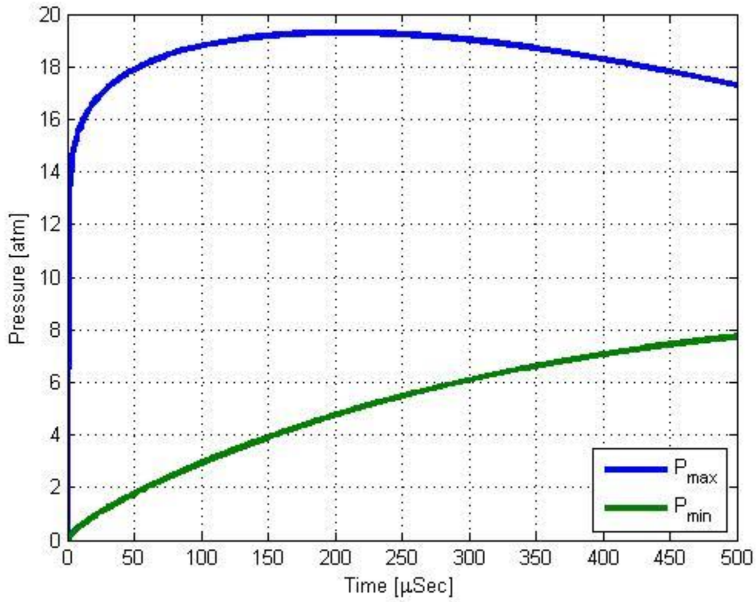

Fig.6: The pressure bounds in the 0÷500 $_{\mu Sec}$ time frame

Fig.6: can now be used as the design space for the pyrotechnic device.
Fig.7: & Fig.8: show the final movement of the piston for using maximum and minimum pressure profiles accordingly:

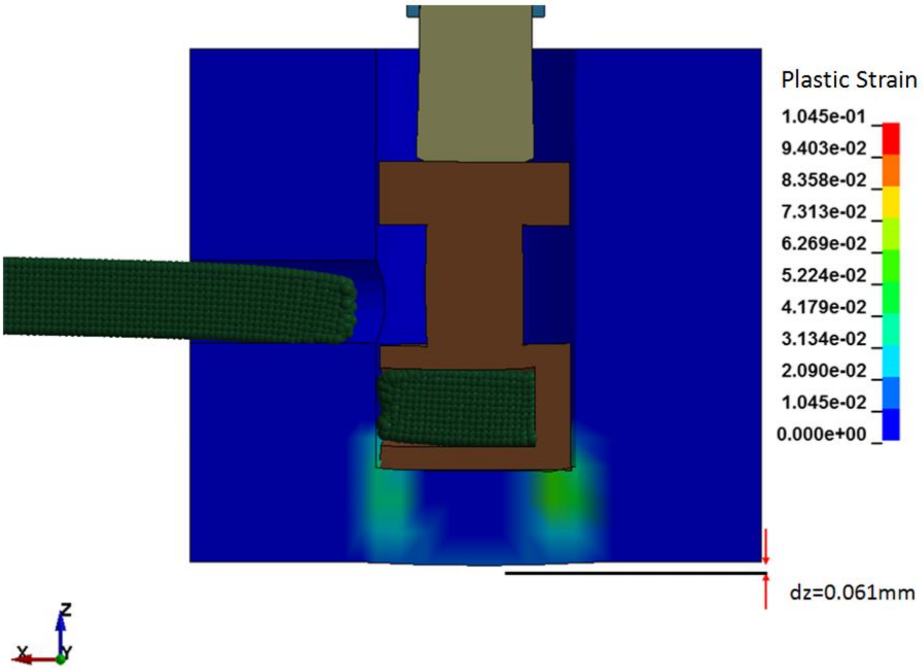

Fig.7: The maximal deflection of the device's base under the upper bound profile

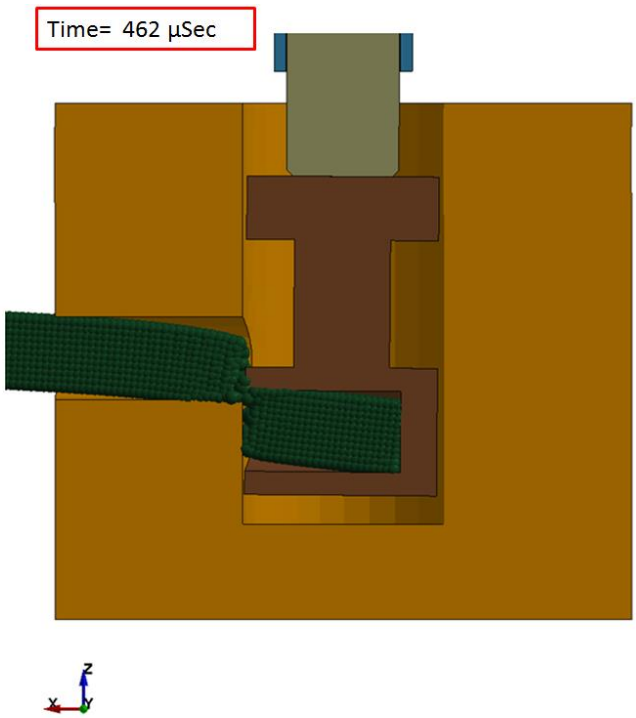

Fig.8: The wire cutting-moment under the lower bound profile

It can be seen in Fig.7: & Fig.8: that both the maximal deflection constraint and maximal cutting time have been achieved.

5 Conclusions

This work presents a methodology of a pyrotechnic device model based design process. It includes an LsDyna numerical model with SPH presentation of the cut wire and two LsOpt tasks.
The work uses the optimization tasks to achieve optimized pressure profiles that will define the "design space" of the pyrotechnic device.
The results presented determine a range of allowable pressure profiles. This was done by taking into account a model that represents the real operating system with constrains.
The range of profile pressures found ensures cutting the wire before reaching 500 µSec (lower boundary), and on the other hand a maximum deflection of the base less than the maximum allowed (upper boundary). The optimization procedure takes into account the change of pressure acting on the piston due to the change in volume in the cylinder during the movement of the piston. The results were translated into pressure profiles with a "Closed Volume" in order to conduct a "Closed Volume" experiment.
This methodology can greatly decrease the number of required experiments needed during the design process.