Microscale SOI/DRIE Delay Mechanisms for Naval Safety and Arming Systems

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Background

Microscale time delay mechanisms (mTDMs) based on SOI/DIRE fabrication techniques are being designed as components of Naval safety and arming (S&A) systems. The μTDMs provide a purely mechanical delay offering a robust and reliable timing mechanism used to arm ordnance a set period after verified launch conditions have been met. Microfabrication technology allows these devices to be integrated with other microscale S&A technologies for complete S&A system at the single chip scale.

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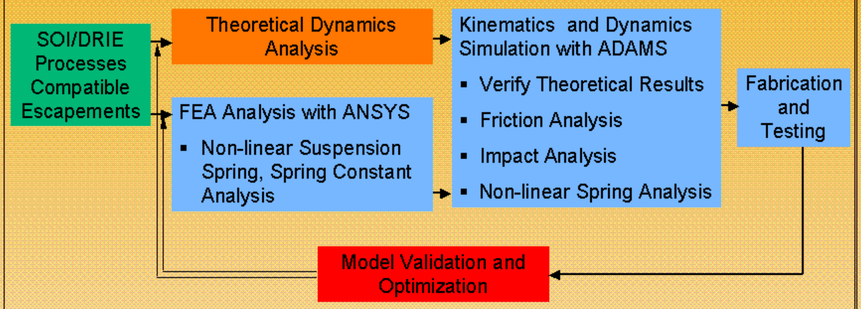
Design Methodology



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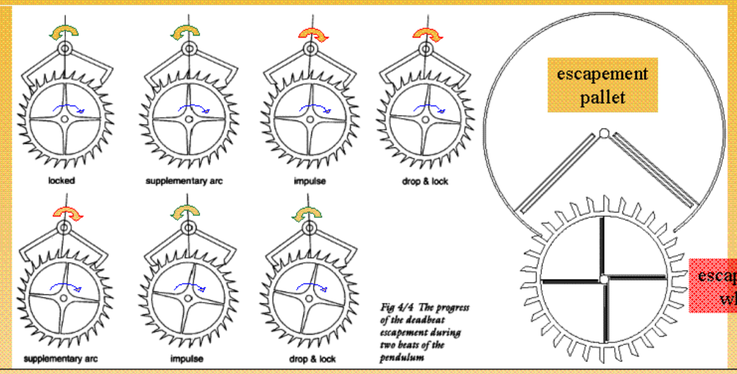
Escapement Operation



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Delay Mechanism Modeling

$$T = \sqrt{\frac{2 I_p \theta}{(M_w - f_w)/n^* - M_b - f_p}}$$

Time delay obtained from every escapement pallet oscillation cycle

$$M_b = m\omega^2 r_s r_p \sin\psi$$

Bias torque counting the influence of projectile rotation to escapement pallet

T: time delay form one teeth matching;
I_p: moment of Inertia of escapement pallet;
θ: rotation angle of escapement pallet;
M_w: torque on escapement wheel;
M_b: bias torque from rotation;
f_w: spring force from escapement wheel suspension structure;
f_p: spring force from escapement pallet suspension structure;

n^*: torque transmission ratio between escapement wheel and escapement pallet;
m: escapement wheel mass;
ω: spin rate of escapement unit;
r_s: c.g. offset from pivot of escapement pallet;
r_p: escapement pallet pivot offset from spin axis;
ψ: included angle between and r_s and r_p

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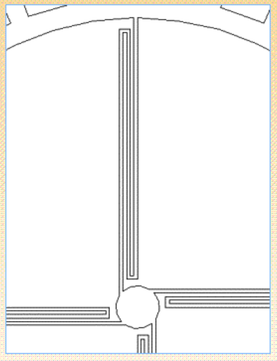
Suspension Spring

To adapt to SOI/DRIE fabrication processes, instead of using pivot (as in macro escapement), suspension springs were used to suspend movable structures from anchors.

Several different spring shapes have been simulated. Folded suspension spring was selected because of its low rotational spring constant and high axial stiffness.



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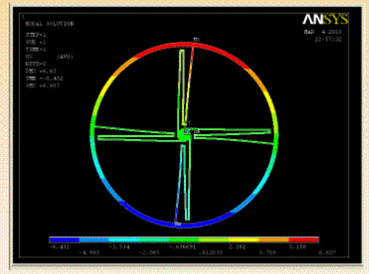
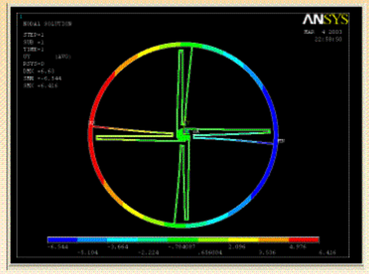
FEA Simulation

Finite element analysis is used to develop accurate spring constants (x,y,z,θ) of suspended escapement wheel and escapement pallet designs:



(a) Deflection in tangential direction



(b) Deflection in radial direction

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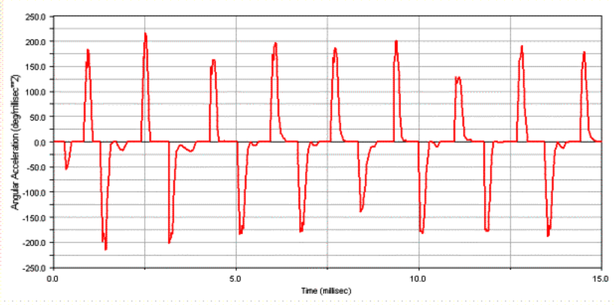
Dynamics Simulation



Escapement pallet acceleration vs. time curve for a typical escapement design. Similar modeling is used to predict total delay times for individual mTDMs.

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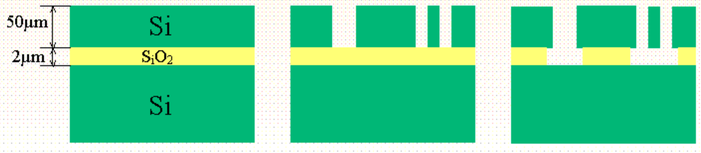
Fabrication Process

Silicon DRIE and SOI technology have been adopted for mTDM fabrication. A single mask process allows low fabrication costs to be realized, potentially making this technology suitable for high-volume submunition applications.



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Summary

- Computer simulations with dynamics and mechanics on the microscale time delay allow us to testify the theoretical results as well as considering impact and friction effects between escapement pallet and escapement wheel. Initial mask designs for test devices are in progress, and fabrication/characterization will follow shortly.
- Detailed models incorporating nonlinear spring effects from the suspended escapement pallet and escapement wheel are being developed for inclusion into the full system models. All critical physical constraints resulting from the SOI/DRIE process, including friction, are being incorporated into both analytical and numerical models. We are also in the process of optimizing μTDM design parameters, including escapement tooth shape and tooth count.

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