**How the EC force response model:**

**Assumptions:**

* Forces act through the COM of the target
  + Could change the center of the current and have the force always act through it
* No delay between a change in the magnet properties and the properties of the induced current
* All current loops are circles
  + Could literally change the shape by parametrically defining the current geometery
  + Could have some sort of ‘shape factor’ that change based on
* Time-varying through magnets are sinusoids with a single frequency component

**Todo:**

* Make an equivalent RMS dipole for time varying permanent magnets so that the v x B can always apply
* See if you can make C functions for basic dipole calculations
* Look up how SPHERES models their system and calculates forces
* Look up game modeling of EM physics
* Is it worth it to use green’s theorem to make vxB exist across the curve?
* Do experiments just to see how much geometry affects different things.
  + Know that thickness of plate has a significant effect
* Write up step by step what happens in the model. ID weak points.

**Physics I know happen**

* Shape of eddy currents dependency
  + Orientation of target in external magnetic field
  + Geometry of target
* Impedance of the current loops increases as the frequency increases
  + Current loops act like I-R circuits (Thomson paper LINK)
* Phase difference between Eddy current and magnetic field will always be 90 degrees (emf = -dB/dt and the derivative introduces a 90 degree shift) + shift between voltage and current.
  + <http://en.wikipedia.org/wiki/Electrical_impedance>
  + The larger the inductance of the loop compared to the resistance, the closer arg(Z) gets to 90 degrees, and the closer the phase difference between the current and the magnetic field.
  + What happens in a superconductor? As resistance drops to zero, the real part of the impedance drops to zero. This makes the additional phase shift approach 90 degrees, so you would have eddy currents that are 180 degrees phase shifted.
  + Unfortunately, inductance and resistance of the current loop are path and material dependent, and thus are geometry dependent.
    - <http://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity>
    - Q: how fast do the current loops drop off with distance – ie. how safe is it to approximate the geometry as the tangent plane nearest the actuator

**Observed Behaviors that the model needs to capture:**

Major Ohji Behaviors (all with three magnet setup):

* Increase force magnitude as material thickness increases
  + Achieved by:
* F varies sinusoidally based on the phase difference between the perpendicular and parallel magnets
* F is always repulsive for a single magnet
  + F increases nonlinearly (positive slope – increasing gains) as the current through the single magnet is increased. I bet this is due to changes in the properties.
* Increasing the current through all the magnets increases the magnetiude of the force, positive and negative
* Increasing the current through the back magnet increases the attractice force with diminishing returns
  + There is an inflection point where the repulsive effect of the back magnet on its own current dominates the attractive force from the side magnets
* For the Ohji scenario, increasing the current ratio between the par and perp magnets increases the force
  + Achieved by having each magnet act on each current loop
* As the frequency of the sine waves increases the force increases in magnitude but with diminishing returns

Major Joe Behaviors:

* Force in same direction as velocity of a single moving dipole when the dipole is oriented perpendicular to the target plate
  + Achieved by having the vxB current loops

Spinning magnet behaviors:

* Have a force component in the plane perpendicular to r x w. Need to investigate how much shear vs compression force.

**Walkthrough of model:**

**Magnets**

* + **Properties**
    - Magnets either have a time varying current or a dipole
    - Magnets have both angular and linear velocities
    - Magnets have a position and a direction

**Plates (Targets)**

* **Properties**

**Current Loops**

* Magnets generate associated magnetic fields. The association is important because based on the dynamics of the magnet, the fields have an associated velocity and frequency. These velocities and frequencies determine the properties of the induced current loops.
* The current loops are associated with a magnet because they need to change when the magnet changes. (Is this necessary, do the current loops need to be a persistent object?)
* Each magnet generates 3 orthogonal current loops. The direction (+/-) and magnitude of the current are determined by Faraday’s law. Faraday’s law is applied differently for velocity induced currents and oscillating field induced currents. (Q: is there a good way to translate them so we can calculate both the same way? Is this useful?)
  + For time varying magnetic fields, integrate dot(dB/dt,dA) across the loop surface to find dB/dt.
  + For B fields with a relative velocity integrate around the loop cross(v,B)
  + [**http://en.wikipedia.org/wiki/Lenz%27s\_law**](http://en.wikipedia.org/wiki/Lenz%27s_law)
  + [**http://en.wikipedia.org/wiki/Electromagnetic\_induction**](http://en.wikipedia.org/wiki/Electromagnetic_induction)
  + [**http://en.wikipedia.org/wiki/Eddy\_current**](http://en.wikipedia.org/wiki/Eddy_current)
* Once the loop has current, the Lorentz force law (F = Bxi) is applied at a number of points around the edge of the loop.
  + [**http://en.wikipedia.org/wiki/Lorentz\_force\_law**](http://en.wikipedia.org/wiki/Lorentz_force_law)
  + Because the net current is broken down into orthogonal components the force on each loop will be perpendicular to the loop and you only need to consider the B field in the loop.

**Geometry Considerations**

Geometry comes into play at a number of points

**Algorithm – Parentheses indicate the function/class where the step occurs**

Generate three orthogonal current loops in each target for each magnet in the system.

All vector calculations to create the loops are done in body coordinates.

For each current loop, set the geometric properties of the loop.

Each loop is associated with