Micro Coulomb-Force-Driven Linear Motor Simulation with Air Effect Using an New Overset Finite Element Method

H. Theodore Lin, PhD, PE
Vice President
AMPS Technologies Company, Pittsburgh, PA

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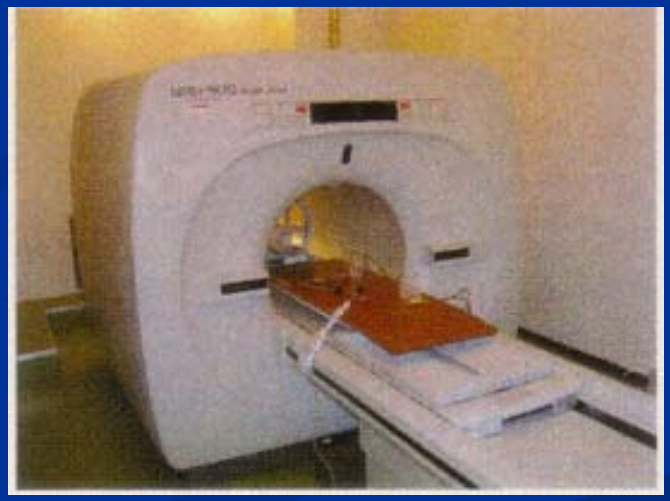
Outline

- Recent linear magnetic motor design problems
- Feature of electrical driven linear motor
- A new finite element Overset method
- Comparing and verifying results between simulation and experiment
- Summary

Magnetic Rotor Design Problems

Magnetic Motor is difficulty to design for good performance in Super Magnetic Field or High Temperature.

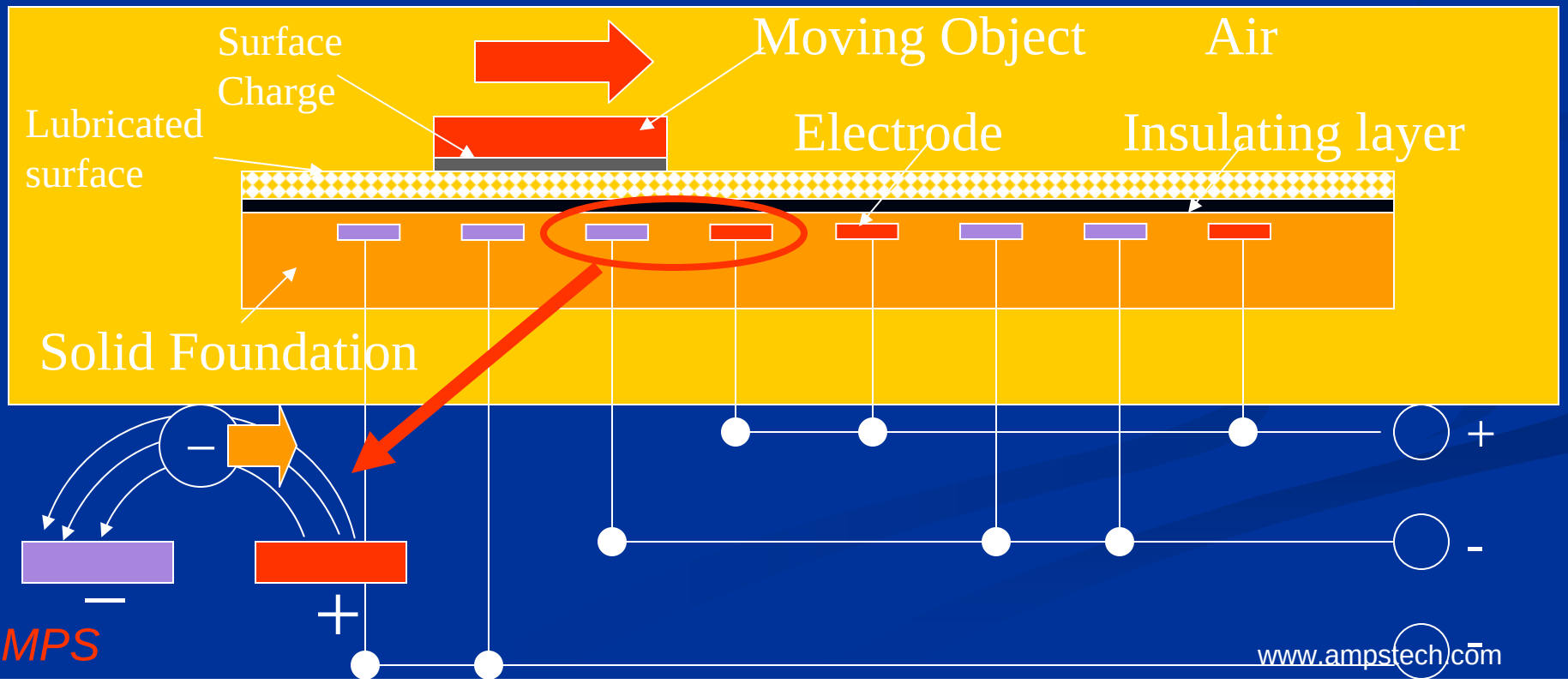
- Super Magnetic Field
  - Require details in shape design to avoid disturbance of Magnetic Field
- High Temperature
  - Permanent magnet's magnetization intensity deteriorates



MRI system

Principle of Electrical Driven Linear Motor

- The moving object is applied with negative charge on the bottom surface.
- Electrodes change voltage sequentially.
- The moving object is driven by the electrical coulomb force generated between positive electrode and negative electrode.



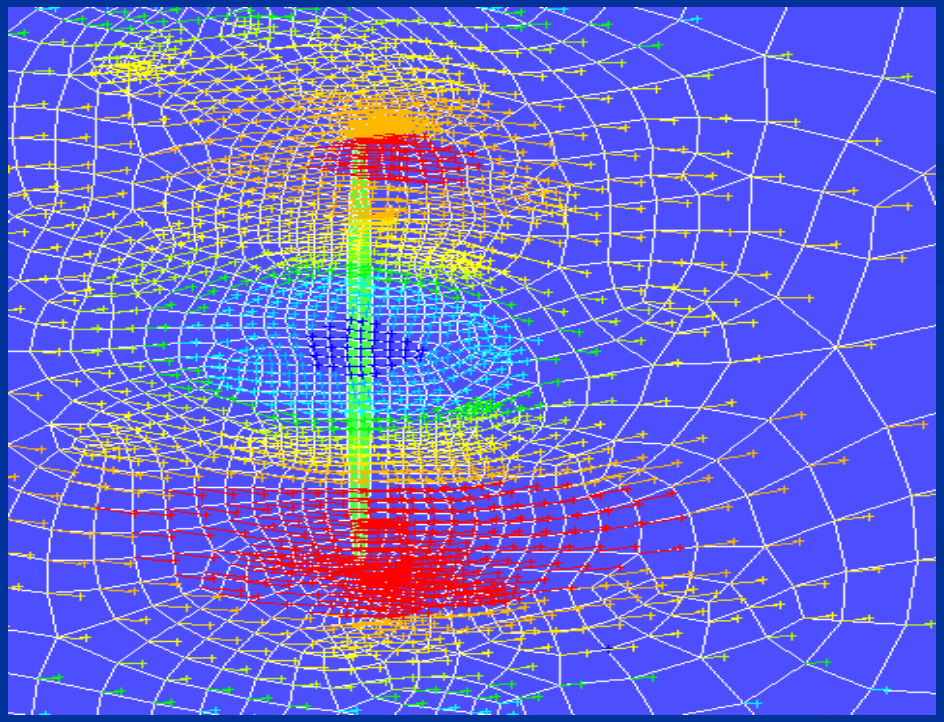
Why Electrical Driven Motor?

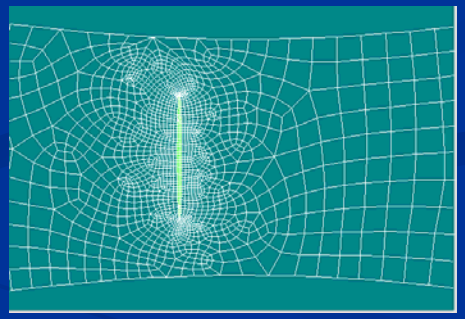
Advantage of Electrical Driven Motor

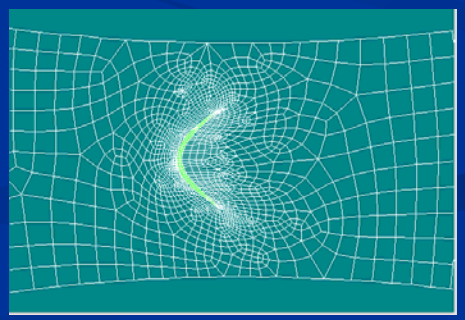
- Can be very lightweight and thin
- Increasing power with more lamination
- No magnetic material involved
- Easy controllable voltage and low current design
- Low magnetic field generation

How to Model Linear Electric Driven Motor?

When traditional ALE method is used, the motion can only move as far as the remeshing algorithm can continue. The required motion from customer is too large for the traditional ALE method to handle

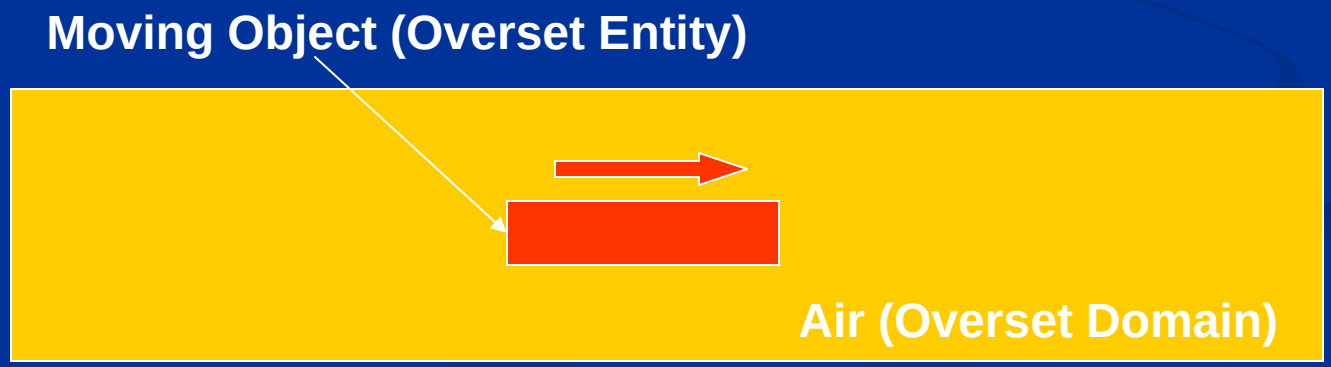






A New Overset Method

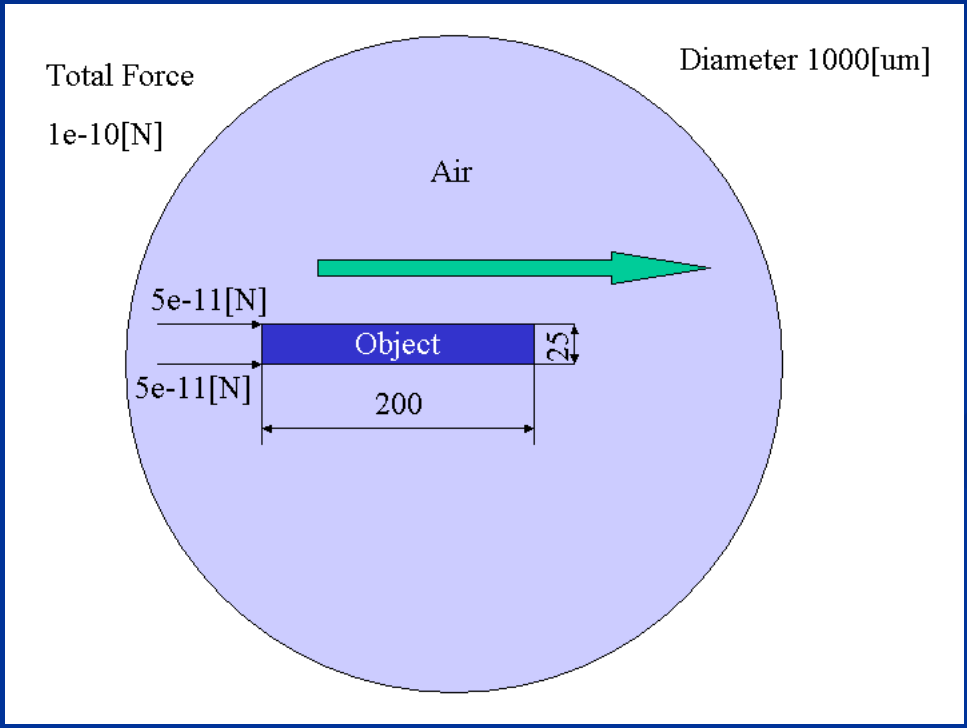
- The problem is analyzed as a transient dielectrical potential problem. Due to the extreme small dimension, the air momentum effect must be considered along with its dielectric property.
- The OverSet method uses two sets of finite elements, and they are referred to as OverSet “Domain” and “Entity”. In this case, the moving object is modeled as OverSet Entity using finite element with both stress and electrical property, and the air is constructed as OverSet Domain based on fluid element (LSFEA based) with dielectrical property



The Overset Method

- Determine the interface position between the air fluid flow and the solid stress region at the beginning of each time step integration
- Apply kinematic constraint of the Domain finite element equations to the Entity's variables to satisfy the *continuity* constraints
- On the fluid-solid interface, the velocity consistency is enforced using a strain-rate based method and a least-squares based incompressible fluid formulation to ensure dynamic equilibrium on the fluid-solid interface
- Repeat the process till convergence is achieved in each time step.

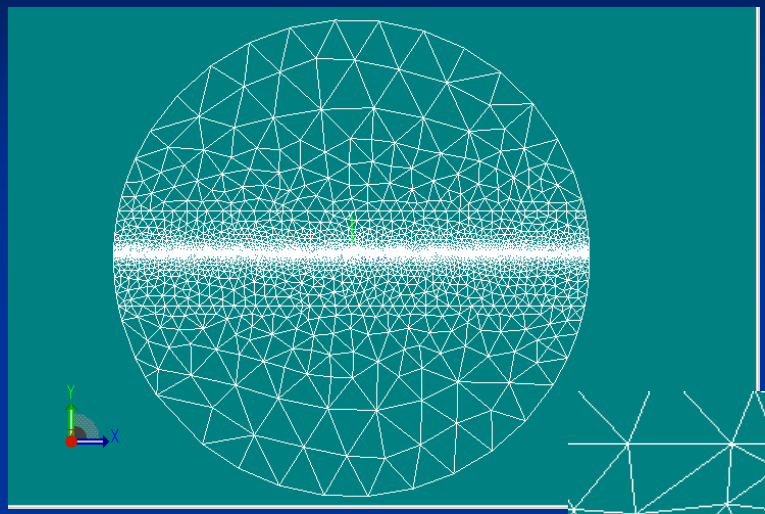
Overset Method Demonstration

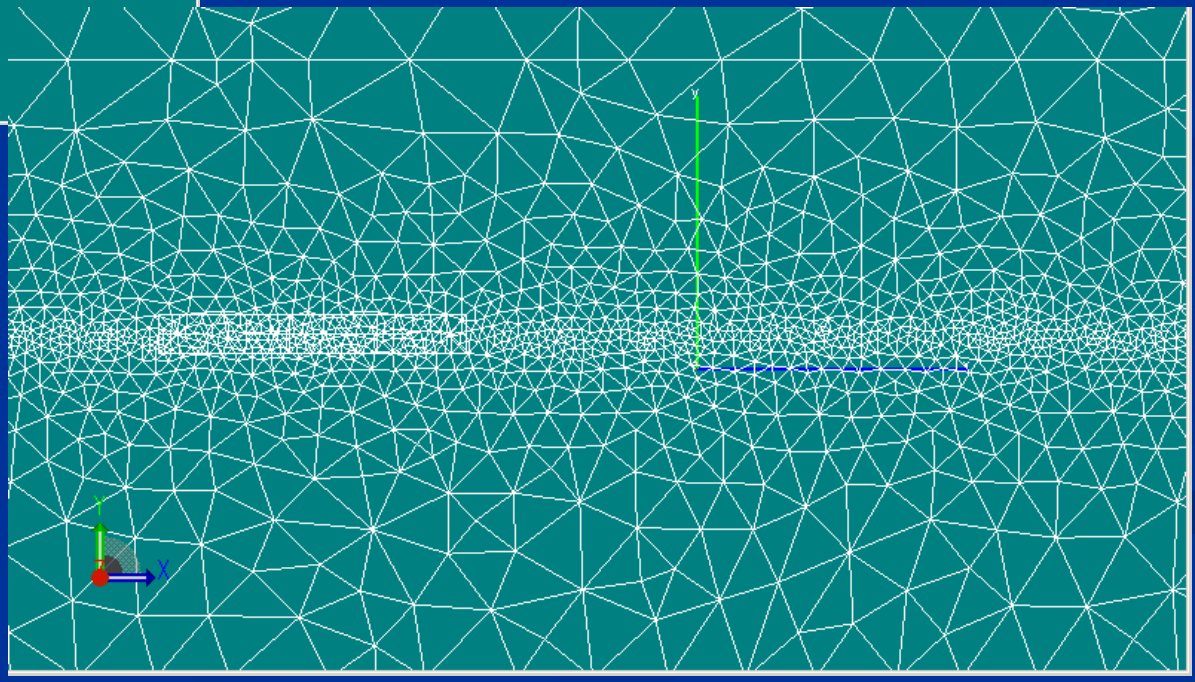


Solid continuum:
Young modulus: 50000e-6[N/μm^2]
Poisson's ratio: 0.29
Mass Density: 2.15e-21 [Nsec/μm^4]

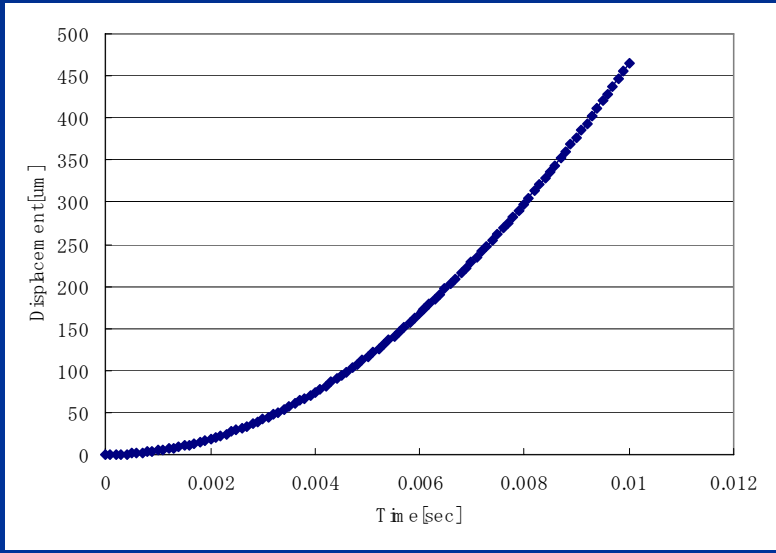
Air :
Viscosity: 1.8e-17[Nsec/μm^2]
Mass Density: 1.2e-24[Nsec/μm^4]

Overset Method Demonstration

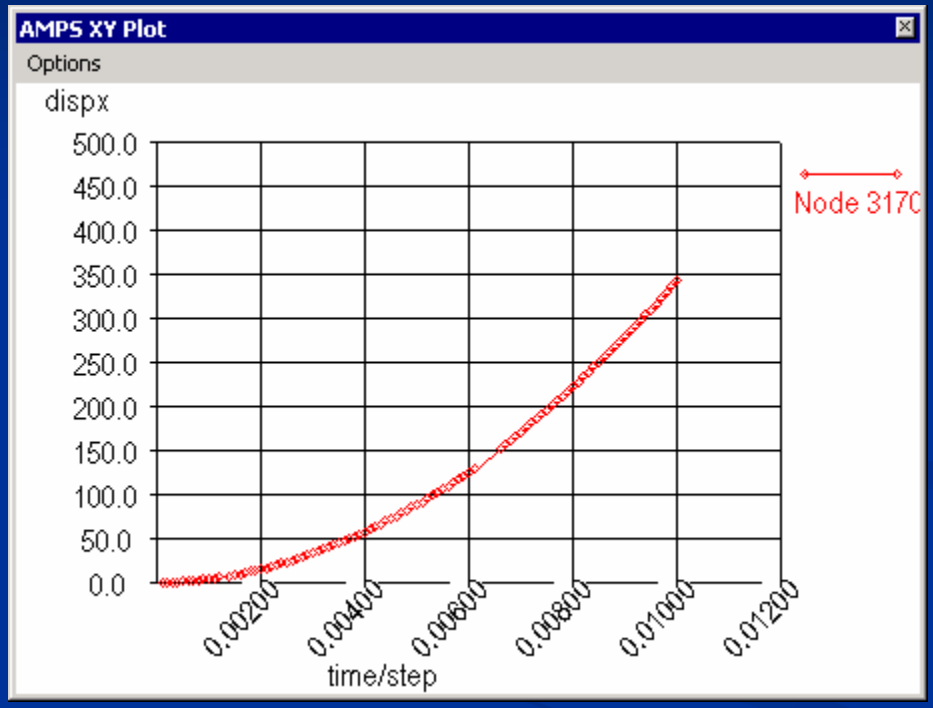




Overset Method Demonstration



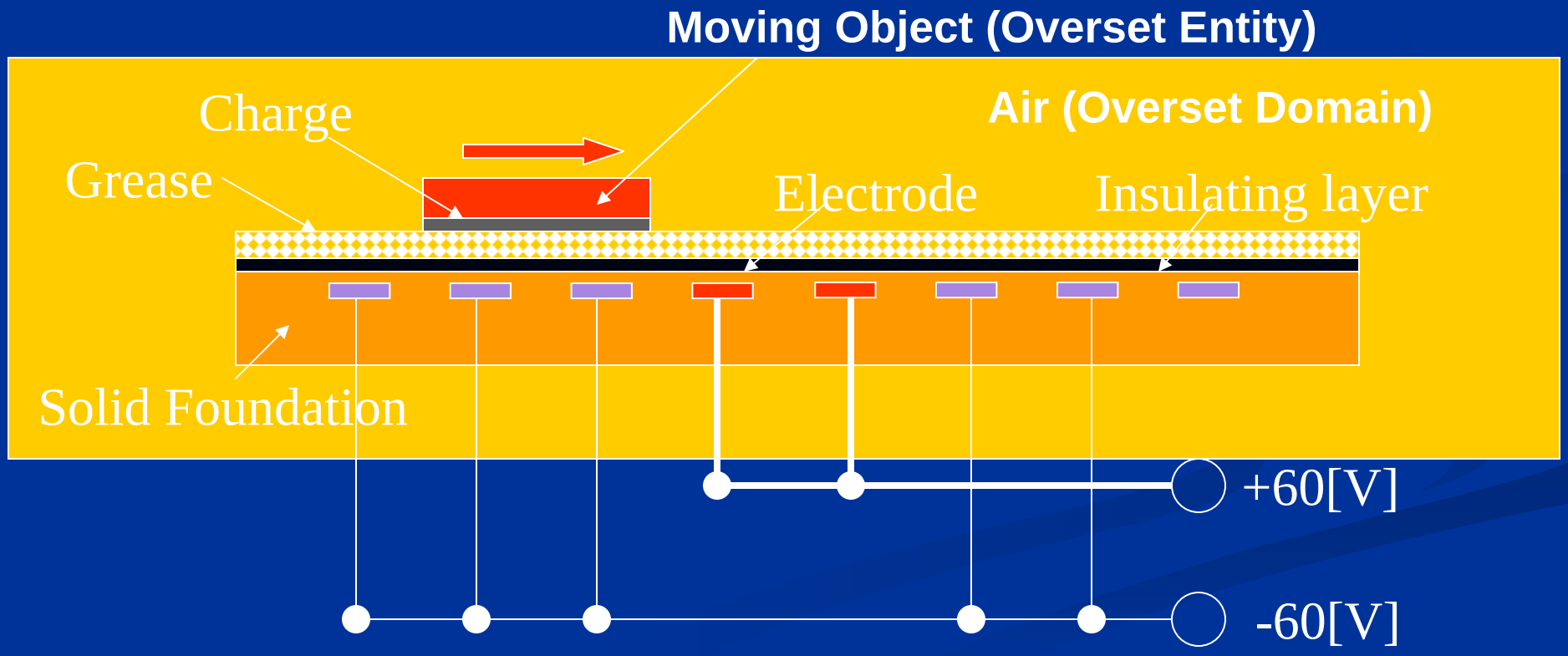
Horizontal displacement without air flow effect (theoretical and numerical results)



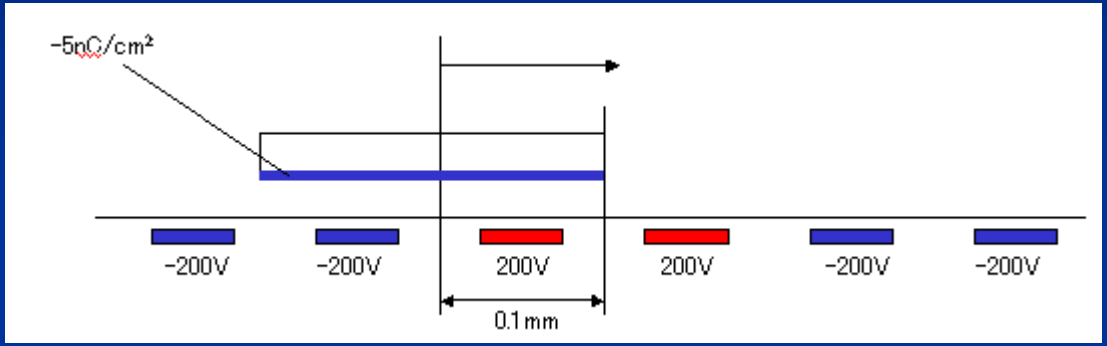
Horizontal displacement with air effect

Experimental validation of simulation model

- The figure shows an experimental test model. This model is applied +60[V] to 2 electrode. The other electrode are applied –60[V].
- Coulomb force calculation based on the surface charge instead of the surface Maxwell stress distribution.

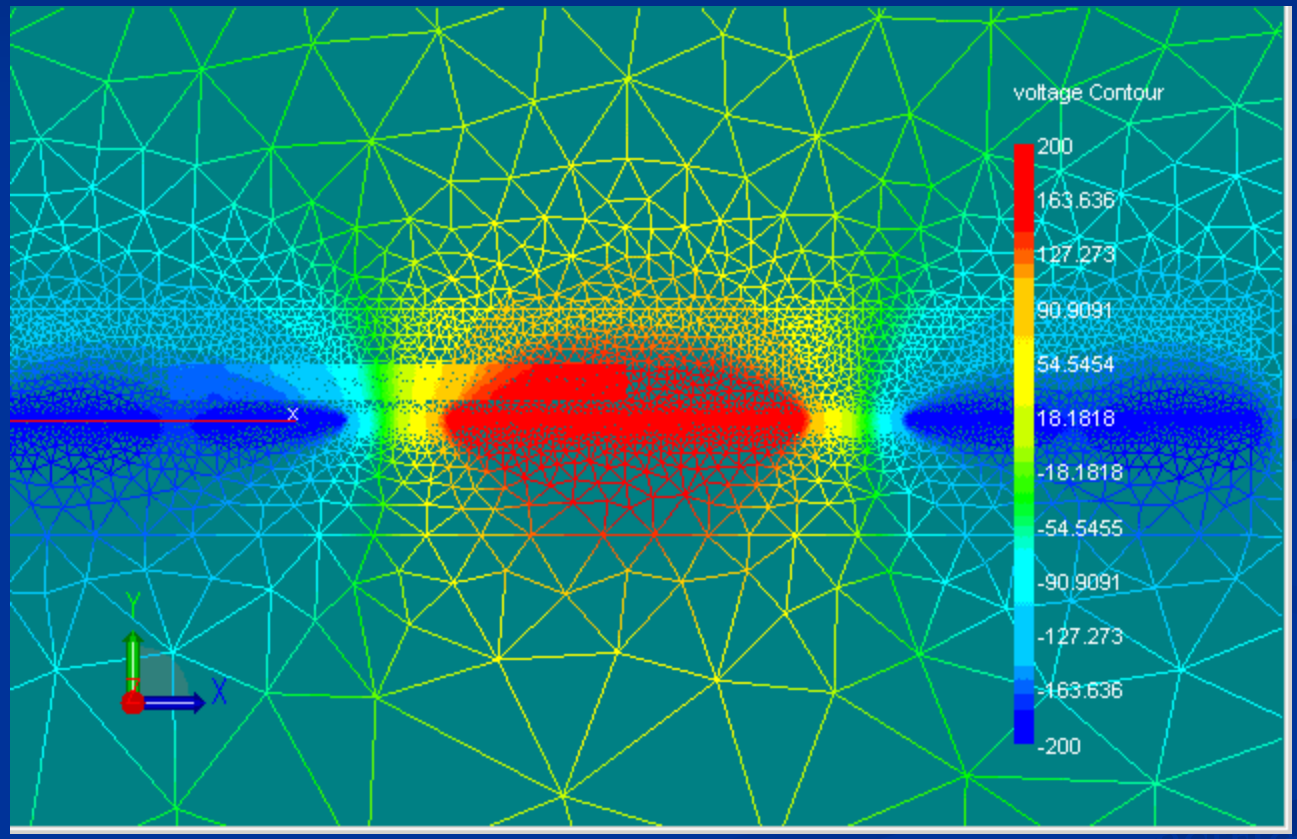


Experimental Validation (courtesy of Olympus Corporation, Japan)



Material Property
Surface Charge: 5e-9[C/cm^2]=5e-5[C/m^2]
Dielectricity of Air: 8.856e-12[F/m]

Experimental Validation (courtesy of Olympus Corporation, Japan)



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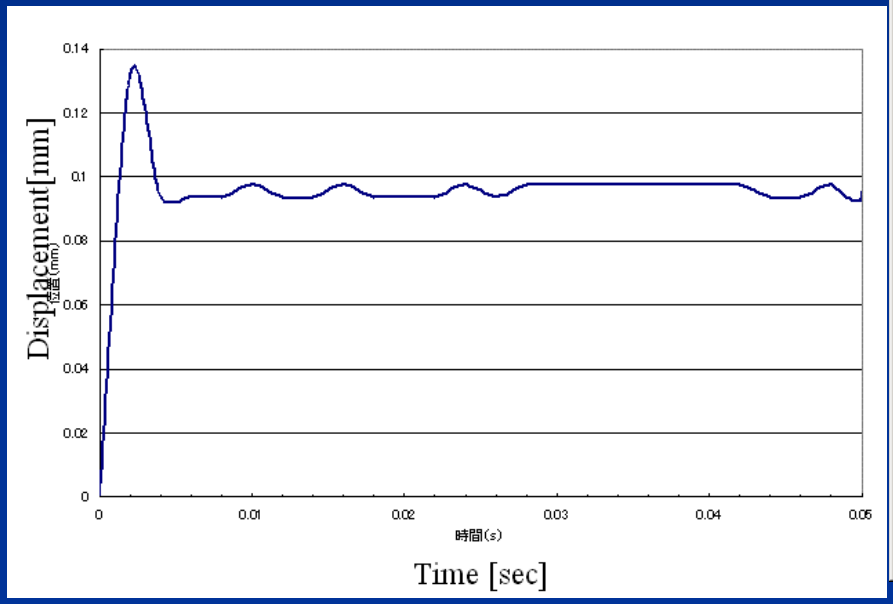
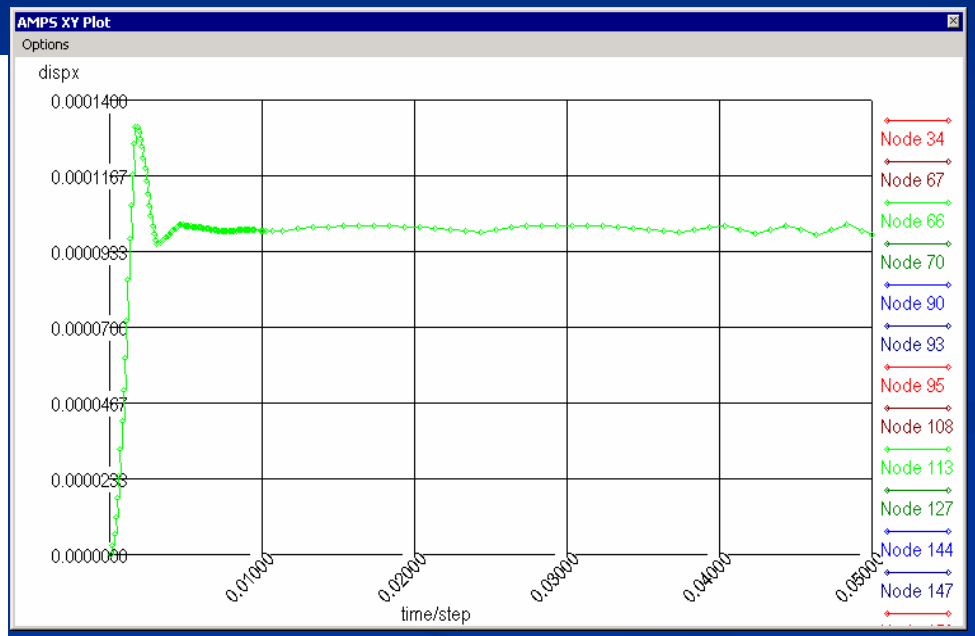


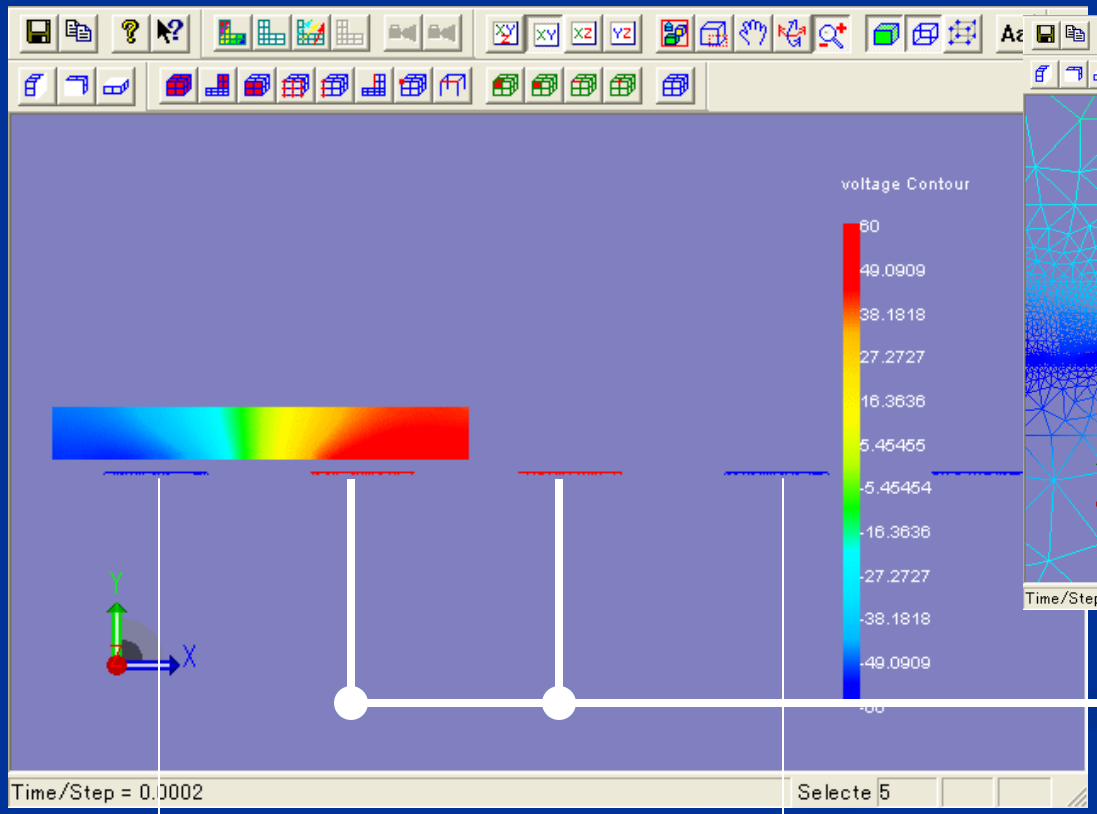


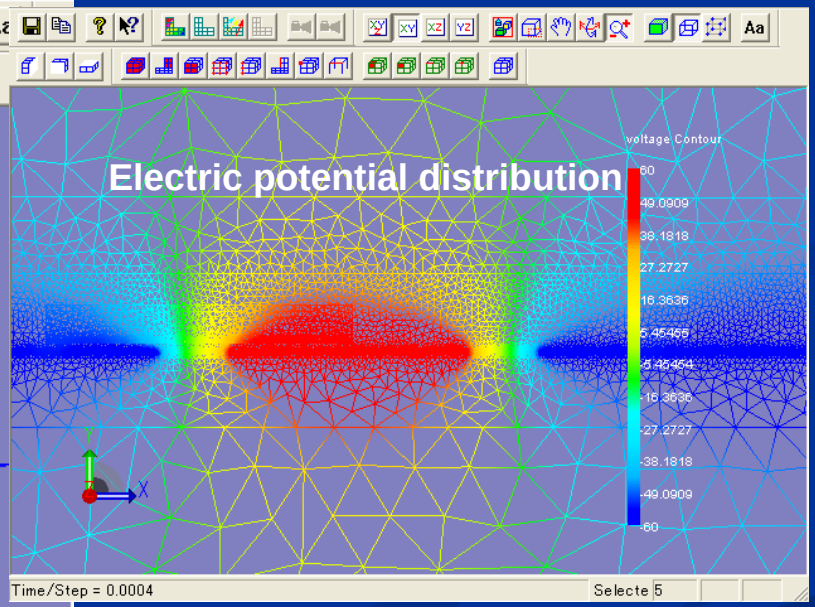
Experimental horizontal displacement

Computed horizontal displacement

Simulation Result for 60[V]

These figures show animation for 60[V].
OverSet “Domain” is fluid (air) and dielectric Field, and then overset “Entity” is charged moving object.





+60[V]

-60[V]

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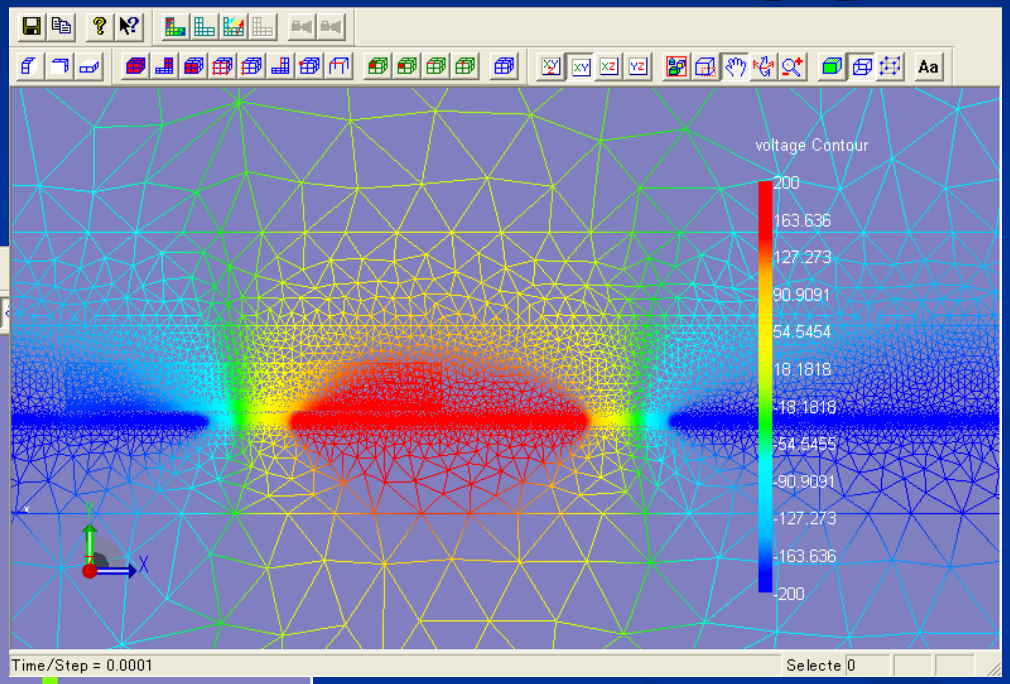
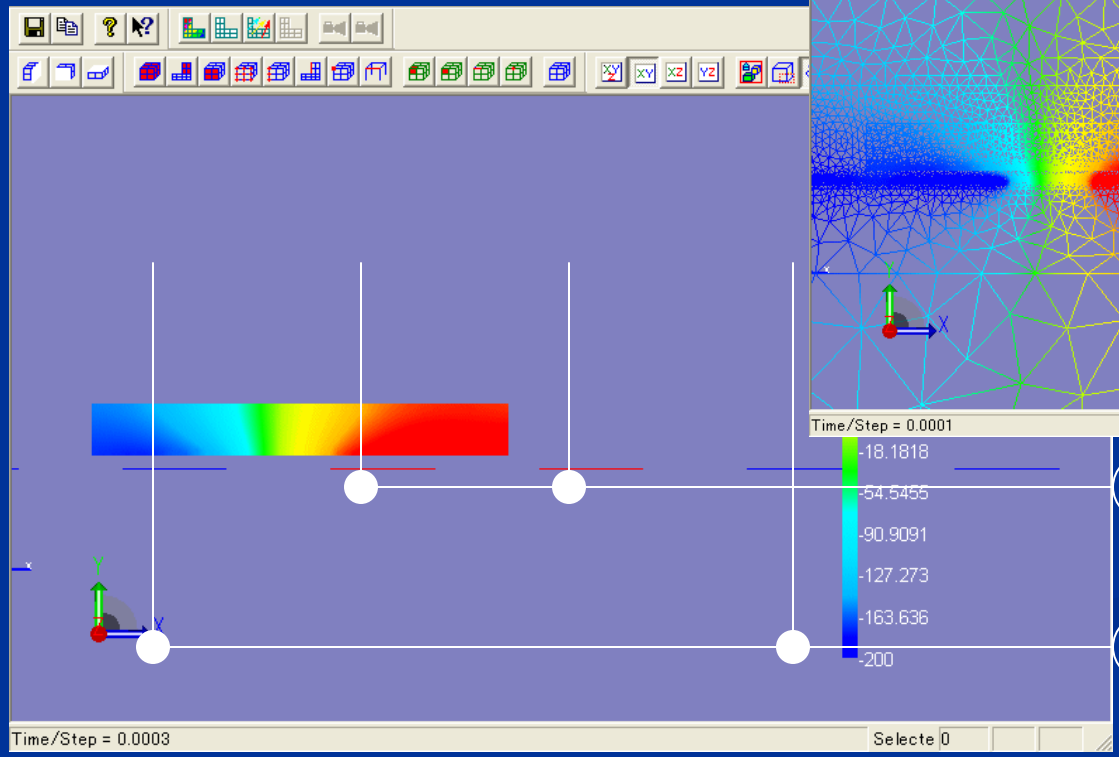
Simulation Result for 200[V]

- These figures show animation for 200[V]

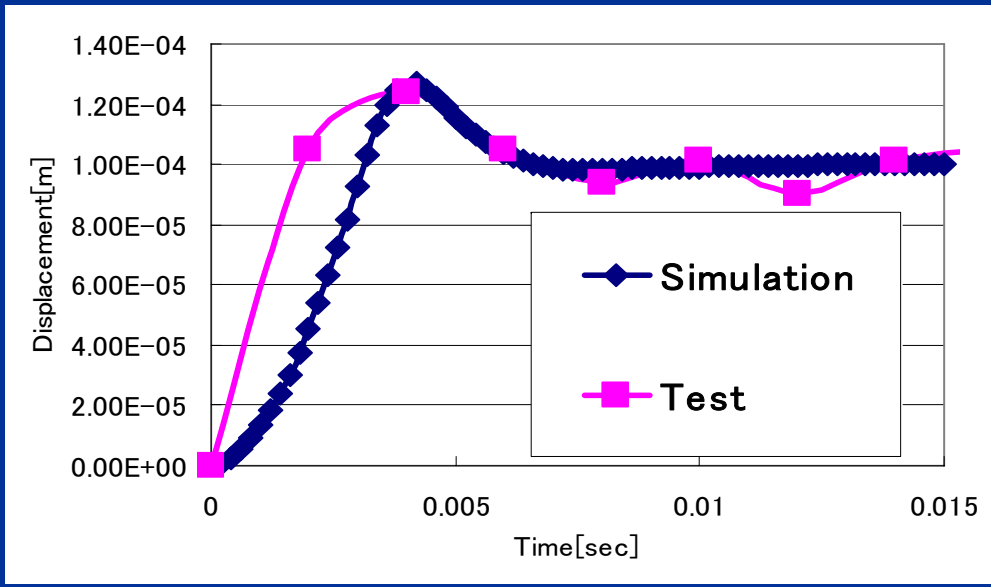


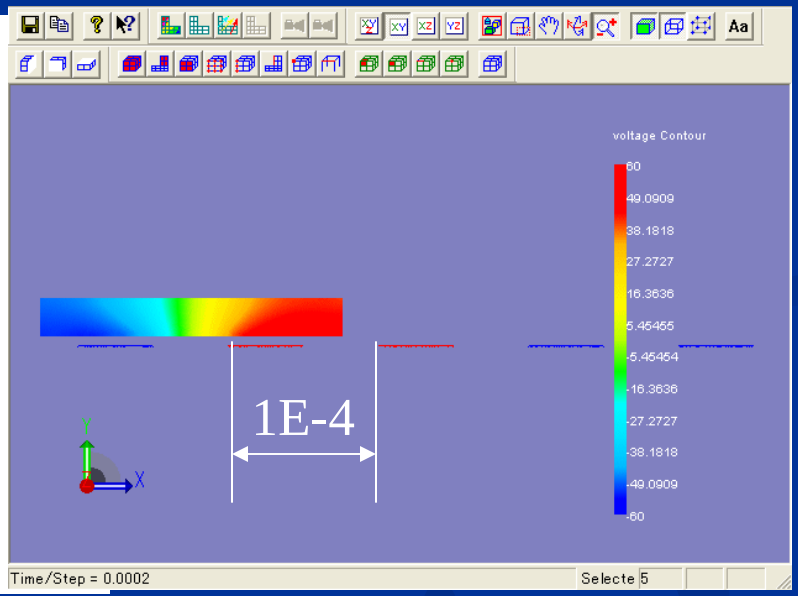


- +200[V]
- -200[V]

Comparing Result of Simulation and Experiment for 60[V]

The response of simulation and experiment for 60[V]

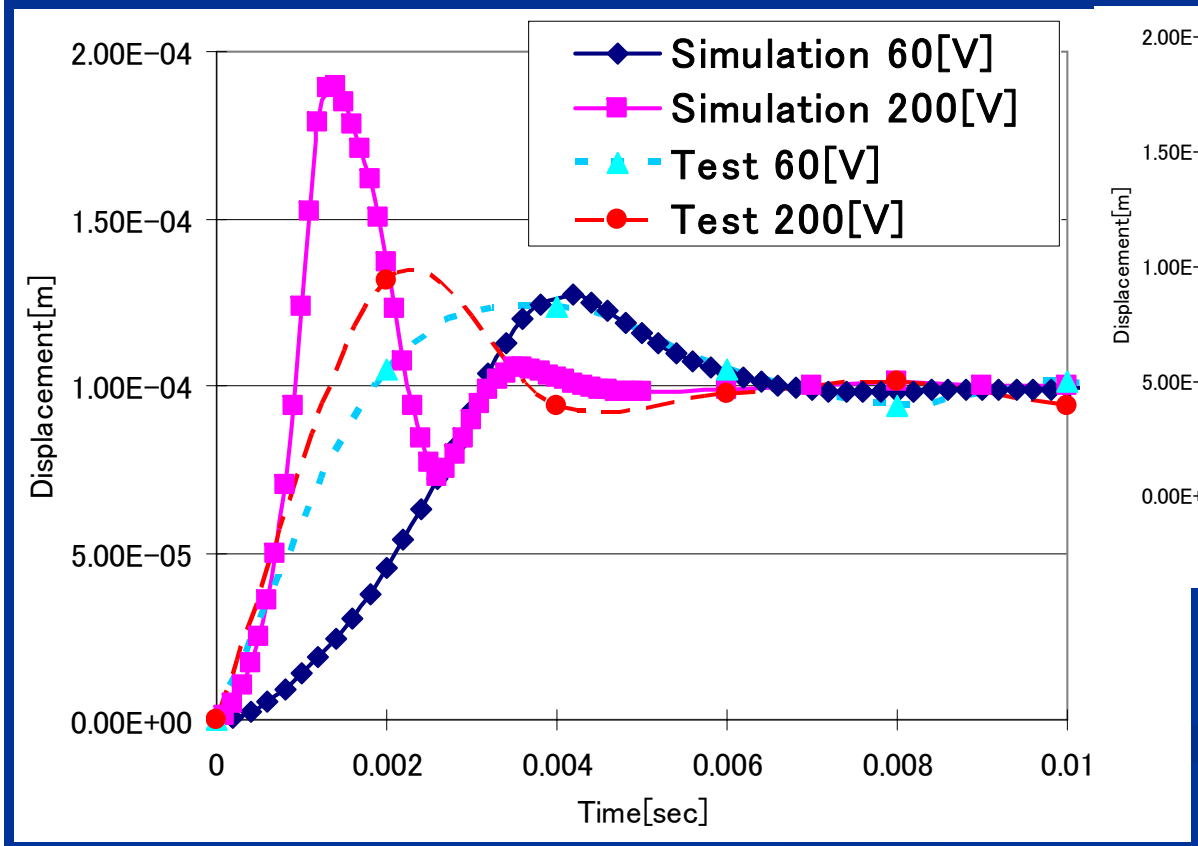


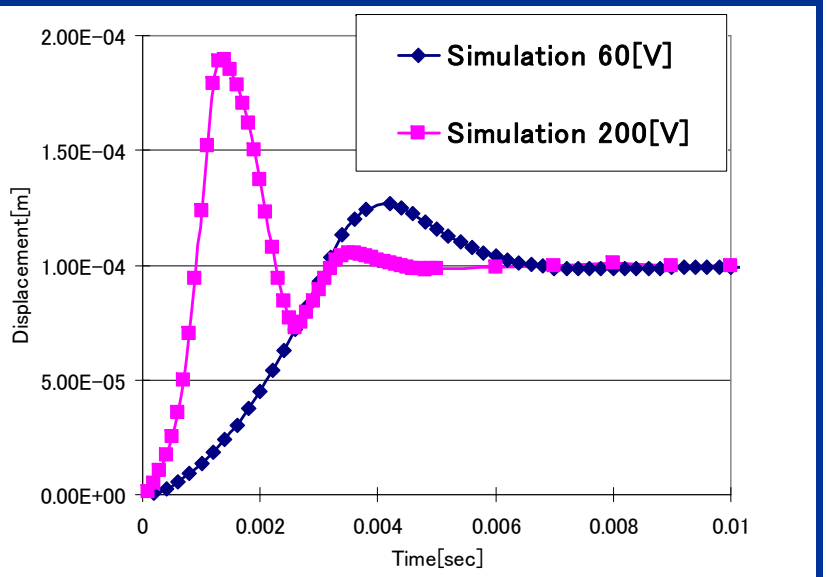


- **The moving object rise time is faster, but the peck value of displacement corresponds with experimental value.**

Response to Voltage change

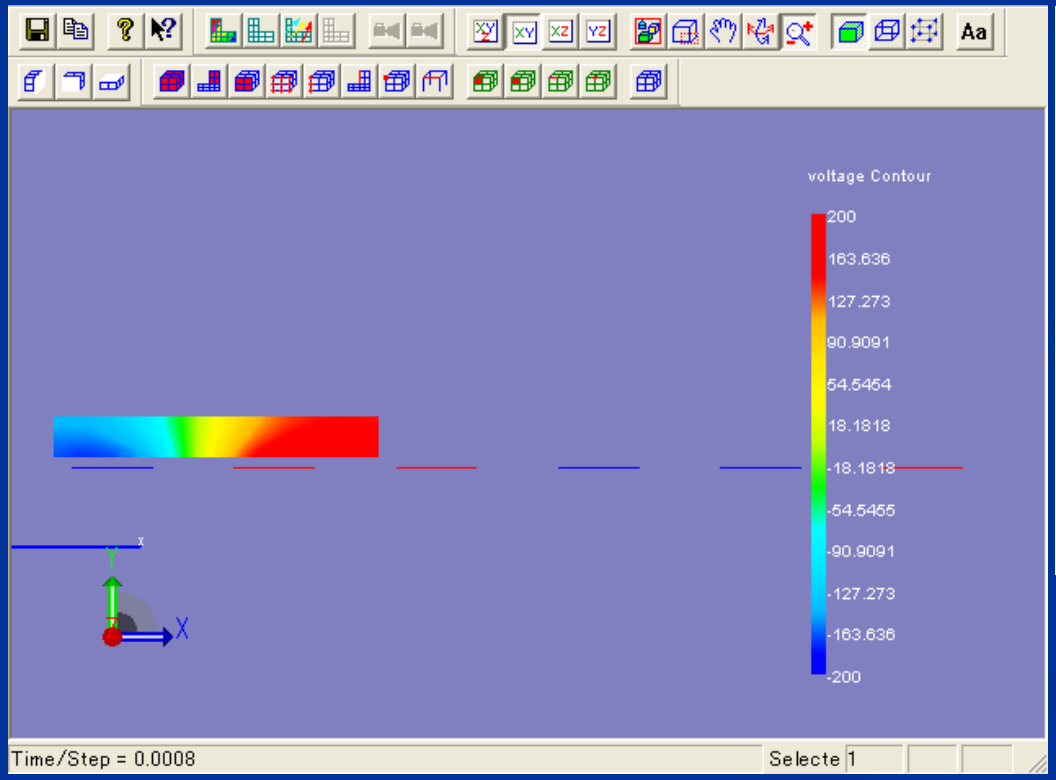
This figure shows response difference between 60[V]and 200[V]. Due to sample rate limitation, the 200[v] results did not match well.

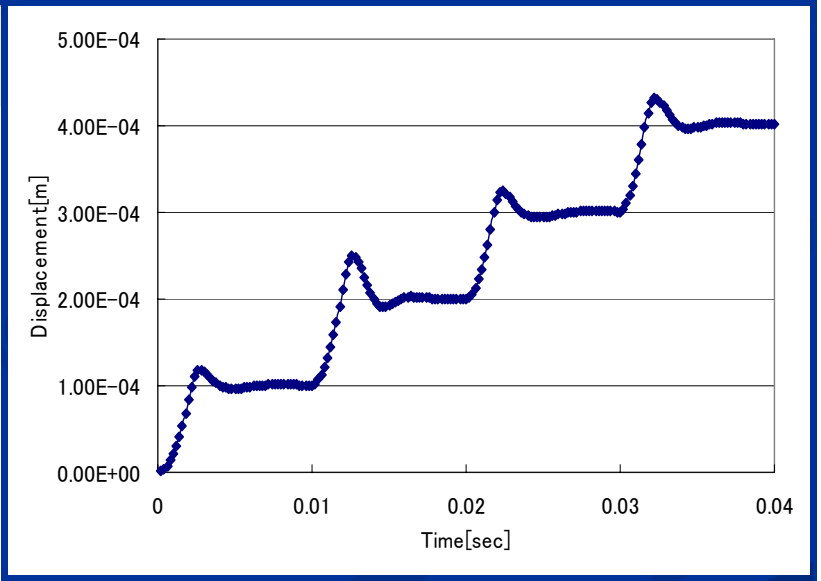




Simulation Result of multi voltage

This response of moving object by varying voltage to each electrode.





Summary

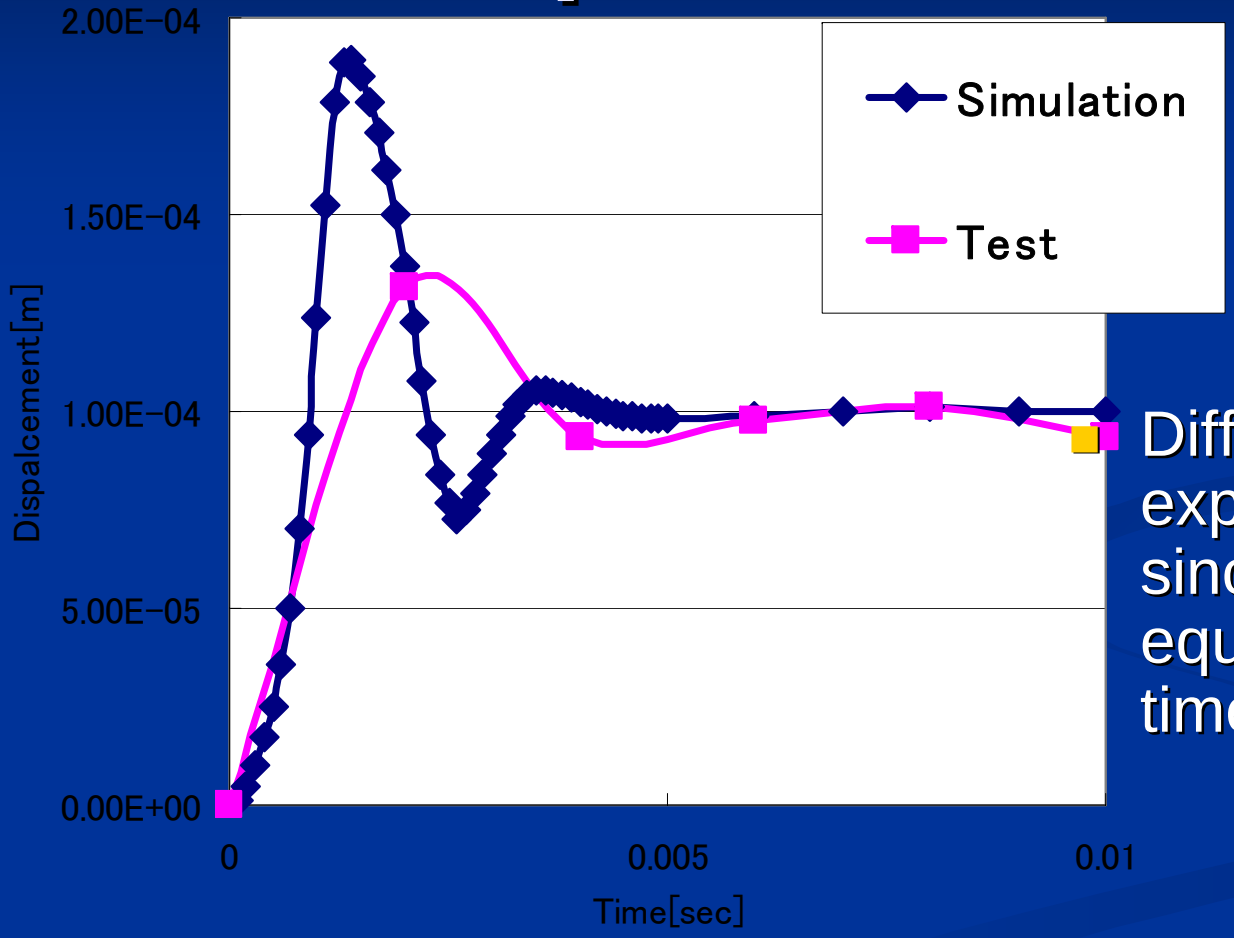
- We created a new Overset method for complex fluid-solid-electrical multiphysics simulations, and compared the experimental and the simulation results for electro driven linear motor.
- Reasonably agreement with experimental results can be extracted from AMPS simulations, and simulation model can be quickly varied to investigate prototype design without engaging expensive empirical testing.
- Detailed Coulomb force can be extracted from simulation results for to better understand design sensitive.
- On going research efforts continue into consideration of various voltage frequency, electrode spacing, mechanical friction, thermal sensitivities, etc.

Appreciation

AMPS Technologies Company would like to thank Olympus Corporation for the opportunity to implement the new Overset method, and the permission to publish these experimental results.

We also appreciate Mr. Tomohiro Soeda, Manager of Advanced Technologies Co. Ltd., Tokyo, Japan, for providing the AMPS models and results, and the tireless efforts in helping us to communicate and to reach many valuable customers.

Comparing result Simulation with Experiment for 200[V]



Difficult to get good experimental result since the equipment sample time is too large.