SIEMENS

ARRAYCON

GUI Tool & FEM modeling

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GUI tool

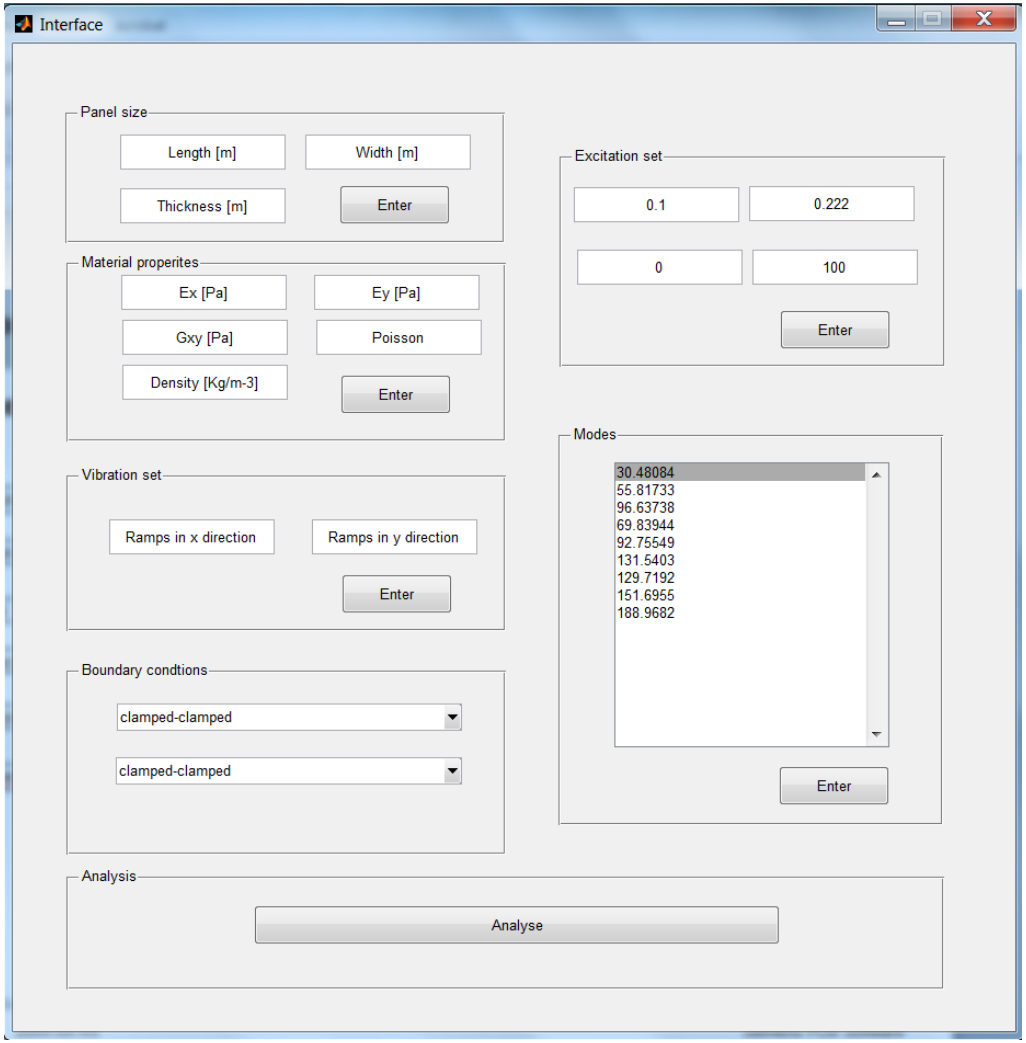
Summary

- Calculate the eigen functions/values
  - Isotropic/orthotropic plate
  - Multiple boundary conditions
- Illustrate physical modes
  - Single modes
  - Modes super-position
- Simulate the excitation response
  - Without damping
  - Chose excitation location
  - Chose exciting time and measure time

GUI tool

Interface

- Plate size
- Vibration set
- Material
- Boundary condition
- Excitation set
- Eigenfrequencies & modes



How does it work?!

Interface

Plate size

Material

Vibration set

+

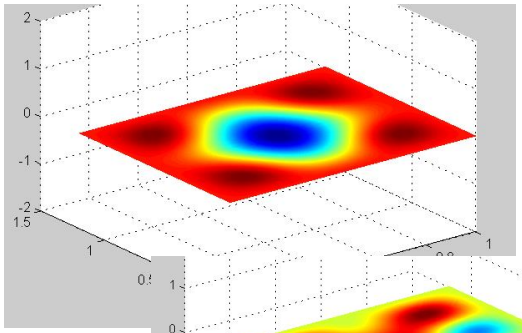
X: Clmaped-Clamped
Clamped Supported
Clamped_free
Supported-Supported
Free-Free

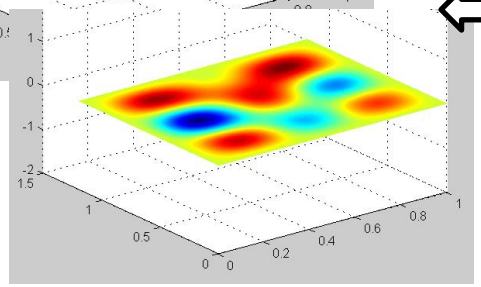
Y: Clmaped-Clamped
Clamped Supported
Clamped_free
Supported-Supported
Free-Free

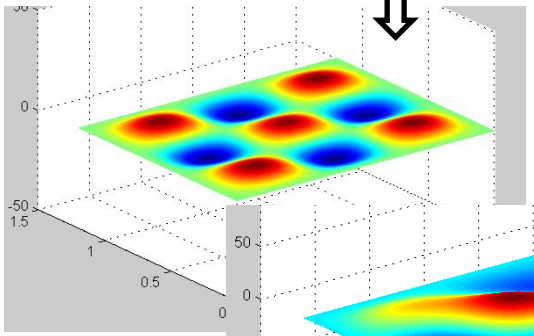
+

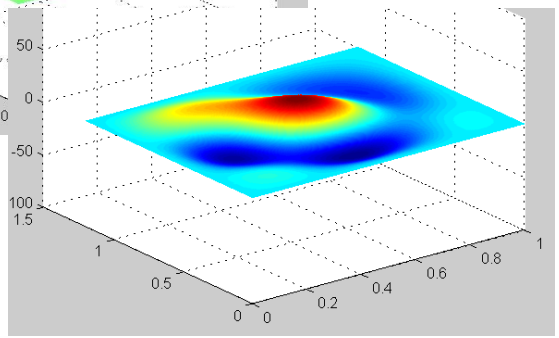
Excitation set

Eigenfrequencies & mode shapes









Green function

Deflection of the plate

$$W_{(x,y,t)} = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} \phi_m(x)\psi_n(y)C_{mn}e^{j\Omega_{mn}t}$$

Velocity:

$$\dot{W}_{(\bar{x},\bar{y},t)} = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} j\Omega_{mn}\phi_m(\bar{x})\psi_n(\bar{y})C_{mn}e^{j\Omega_{mn}t}$$

Initial condition:

$$\dot{W}_{(\bar{x},\bar{y},0)} = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} j\Omega_{mn}\phi_m(x)\psi_n(y)C_{mn}$$

$$\Rightarrow C_{mn} = \frac{1}{j\Omega_{mn}}\iint \dot{W}_{(\bar{x},\bar{y},t=0)}\phi_m(\bar{x})\psi_n(\bar{y})d\bar{x}d\bar{y}$$

Green function

Deflection of the plate:

$$W_{(x,y,t)} = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} \phi_m(x)\psi_n(y)C_{mn}e^{j\Omega_{mn}t}$$

Deflection of the plate with initial condition:

$$W_{(x,y,t)} = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} \phi_m(x)\psi_n(y)e^{j\Omega_{mn}(t)}\frac{1}{j\Omega_{mn}}\iint \dot{W}_{(\bar{x},\bar{y},0)}\phi_m(\bar{x})\psi_n(\bar{y})d\bar{x}d\bar{y}$$

Deflection of the plate with initial condition:

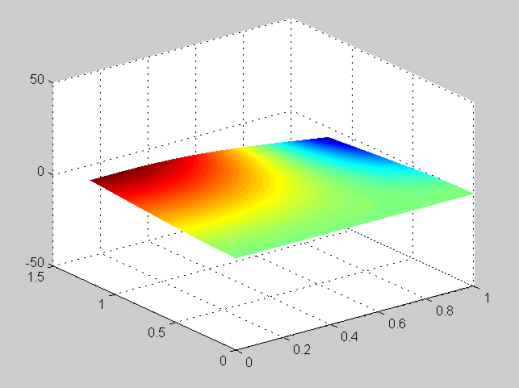
$$W_{(x,y,t)} = \int \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} \phi_m(x)\psi_n(y)e^{j\Omega_{mn}(t-\tau)}\frac{1}{j\Omega_{mn}}\iint f\phi_m(\bar{x})\psi_n(\bar{y})d\bar{x}d\bar{y}\,d\tau$$

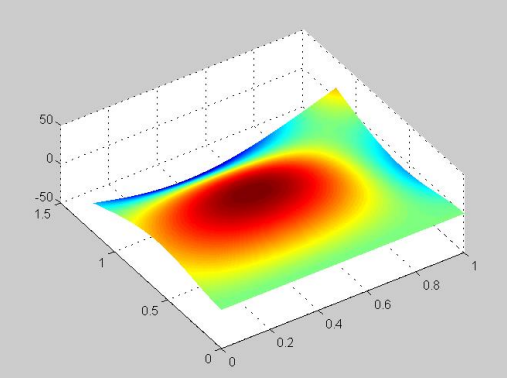
Different boundary conditions mode shape

CFFF & CFCF

74.3Hz

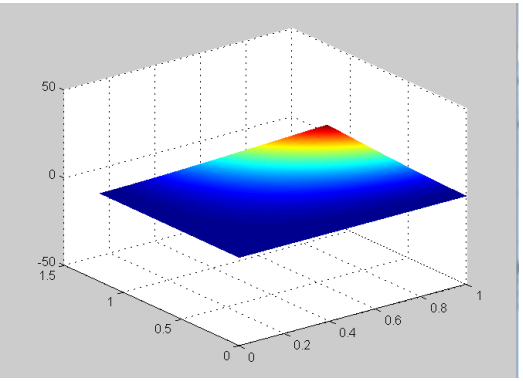
273.9Hz

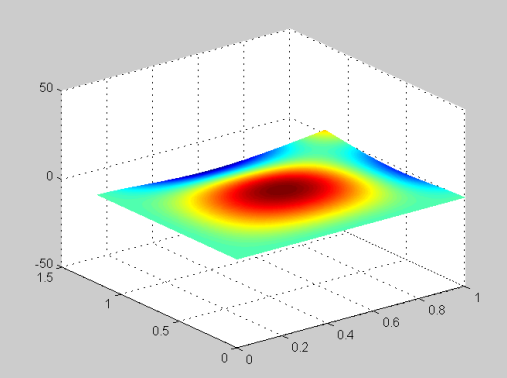




35.3Hz

208.8Hz



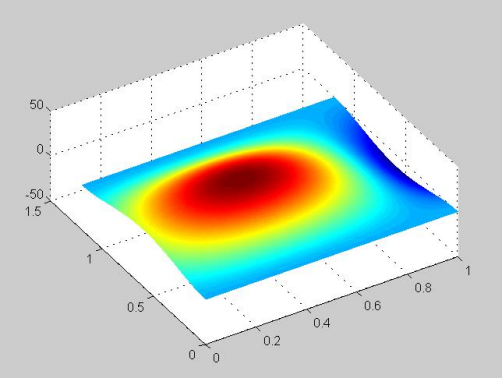


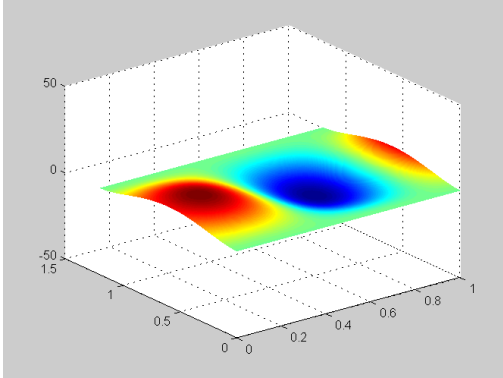
Different boundary conditions mode shape

CCFF & CCSS

275.2Hz

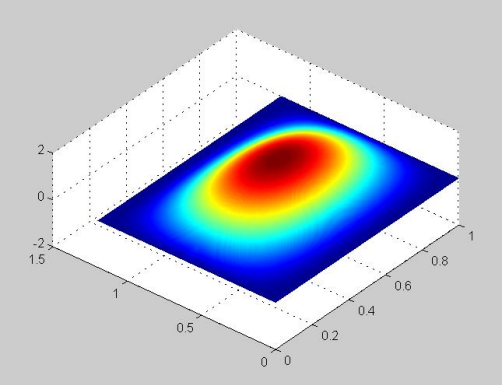
449.7Hz

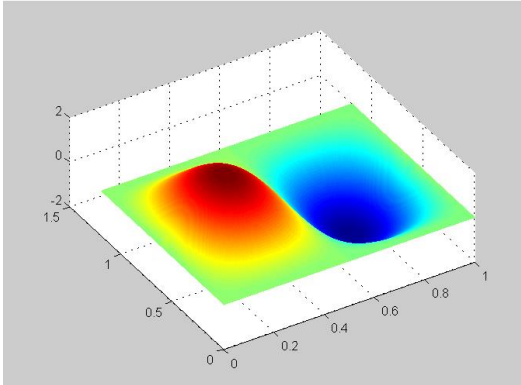




235.48Hz

470.8Hz



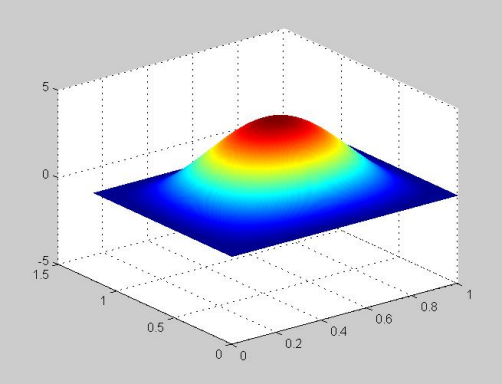


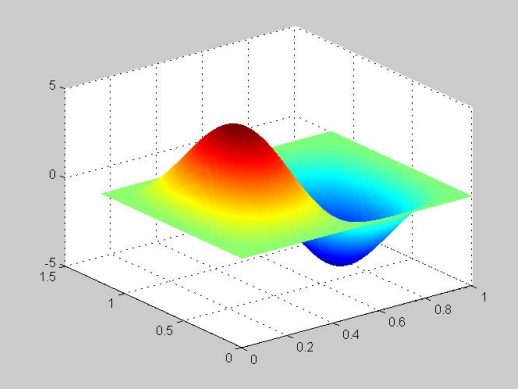
Different boundary conditions mode shape

CCCC & SSSS

309.5Hz

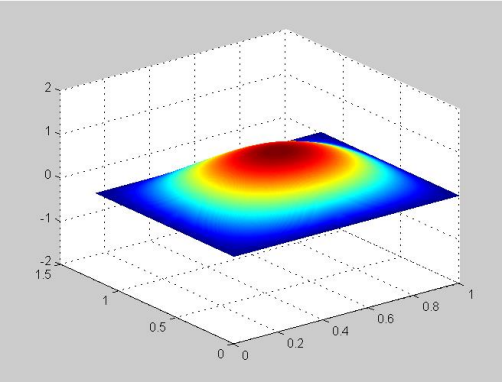
566.8Hz

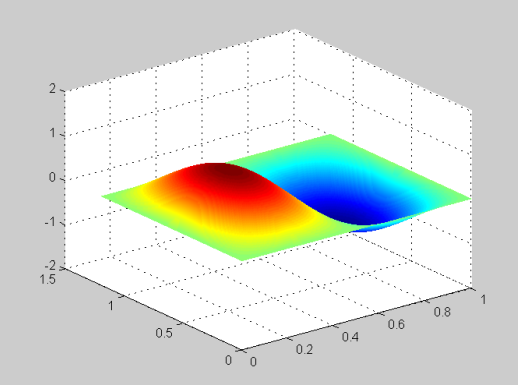




172.1Hz

383.8Hz

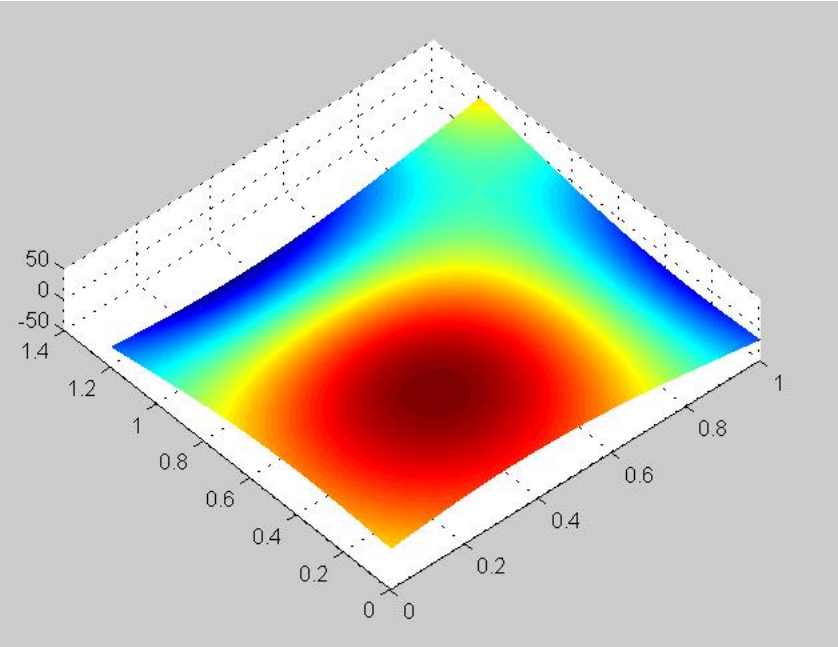




FFFF mode shape…

Boundary condition: free-free

- Not a symmetric from
  - No spacial restraint
  - Depend on the initial value of the Newton iteration method in the code



Piezoelectric effect coupling

For the plate:

Neutral surface location

$$\int_{-\frac{t_s}{2}}^{\frac{t_s}{2}} \frac{E_s(z-\delta)}{r} dz + \int_{\frac{t_s}{2}}^{\frac{t_s}{2}+t_p} \frac{E_p(z-\delta)}{r} dz = 0$$

- In plane forces

$$N_x = -K_t \left(\frac{\partial^2 w}{\partial x^2} + \nu_t \frac{\partial^2 w}{\partial y^2} \right) + \int_{\frac{t_s}{2}}^{\frac{t_s}{2}+t_p} e_3 d_{31} dz = 0$$

$$N_y = -K_t \left(\frac{\partial^2 w}{\partial y^2} + \nu_t \frac{\partial^2 w}{\partial x^2} \right) + \int_{\frac{t_s}{2}}^{\frac{t_s}{2}+t_p} e_3 d_{32} dz = 0$$

So

$$K_t \left(\frac{\partial^2 w}{\partial x^2} + \nu_t \frac{\partial^2 w}{\partial y^2} \right) = e_3 t_p d_{31}$$

$$K_t \left(\frac{\partial^2 w}{\partial y^2} + \nu_t \frac{\partial^2 w}{\partial x^2} \right) = e_3 t_p d_{32}$$

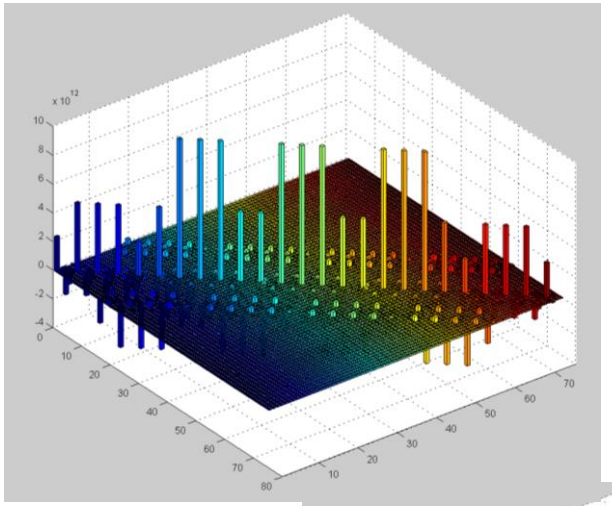
Plate FEM modeling

Mass, stiffness, voltage matrix

$$\mathbf{m} = \int_{V_s} \mathbf{B}_{\boldsymbol{\eta}}^t \mathbf{Z}^t \rho_s \mathbf{Z} \mathbf{B}_{\boldsymbol{\eta}} \, \mathrm{d}V_s + \int_{V_p} \mathbf{B}_{\boldsymbol{\eta}}^t \mathbf{Z}^t \rho_p \mathbf{Z} \mathbf{B}_{\boldsymbol{\eta}} \, \mathrm{d}V_p$$

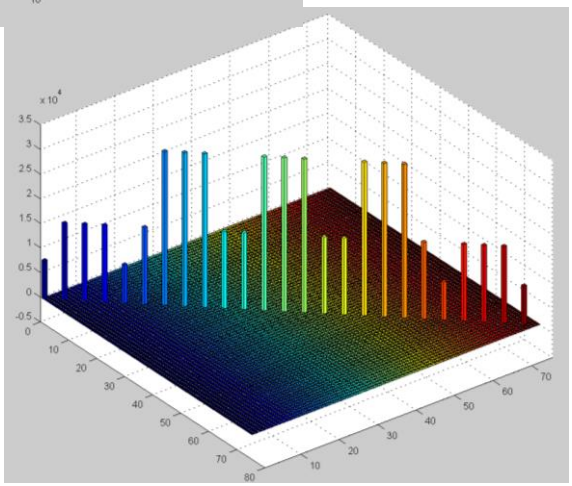
$$\mathbf{k} = \int_{V_s} z^2 \mathbf{B}_{\boldsymbol{\kappa}}^t \bar{\mathbf{c}}_s \mathbf{B}_{\boldsymbol{\kappa}} \, \mathrm{d}V_s + \int_{V_p} z^2 \mathbf{B}_{\boldsymbol{\kappa}}^t \bar{\mathbf{c}}_p^E \mathbf{B}_{\boldsymbol{\kappa}} \, \mathrm{d}V_p$$

$$\boldsymbol{\theta} = \int_{V_p} z \mathbf{B}_{\boldsymbol{\kappa}}^t \bar{\mathbf{e}}^t \mathbf{B}_{\mathbf{E}} \, \mathrm{d}V_p$$



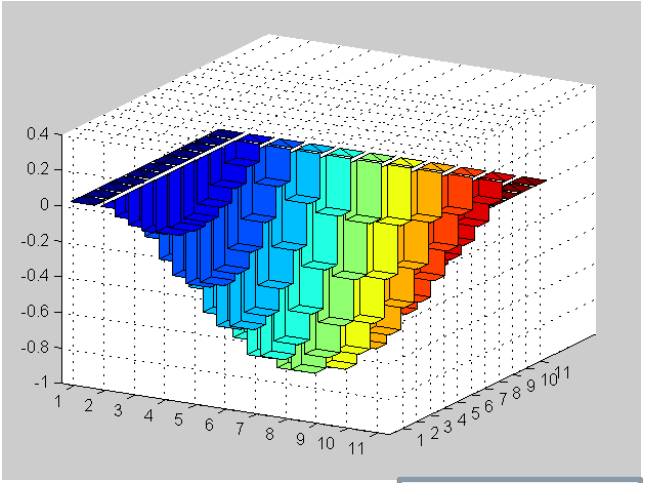
$$\mathbf{M}\ddot{\boldsymbol{\Psi}} + \mathbf{C}\dot{\boldsymbol{\Psi}} + \mathbf{K}\boldsymbol{\Psi} - \boldsymbol{\Theta}\mathbf{v} = \mathbf{F}$$

$$\mathbf{C}_p\mathbf{v} + \mathbf{Q} + \boldsymbol{\Theta}^{\mathrm{t}}\boldsymbol{\Psi} = 0$$

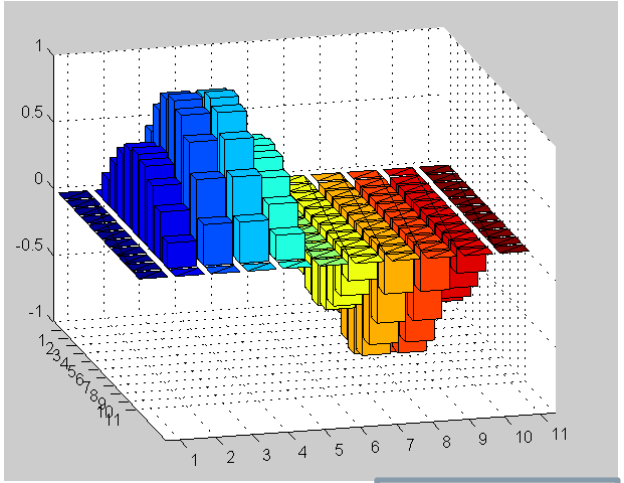


First results

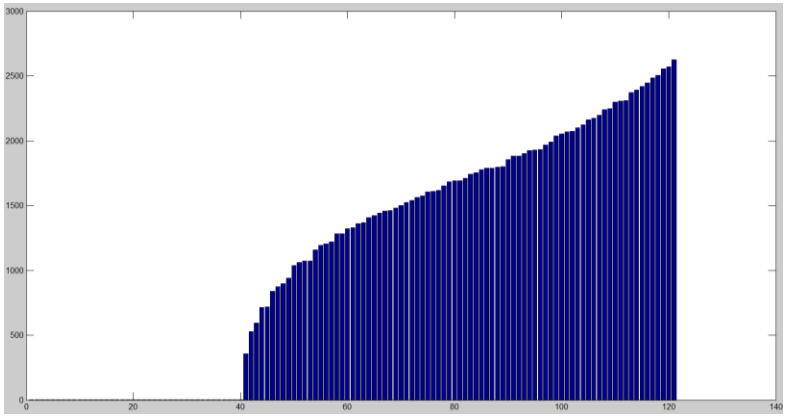
First two mode shapes by FEM without electromechanical coupling

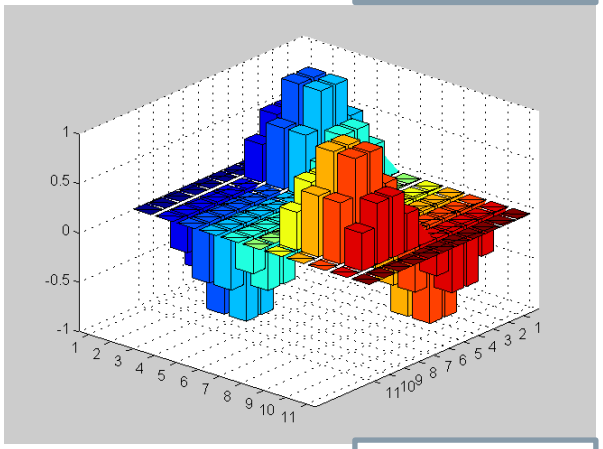


357.9Hz



526.7Hz





716.2Hz

Improving

Summary

- GUI tool
  - Calculation Method (Newton)
  - Structure of the GUI
- FEM modeling
  - Continuing to work
  - Piezoelectric effect coupling
- Paper
  - Result of the mechanical effect by adding extra patches
  - FEM modeling result