Control System

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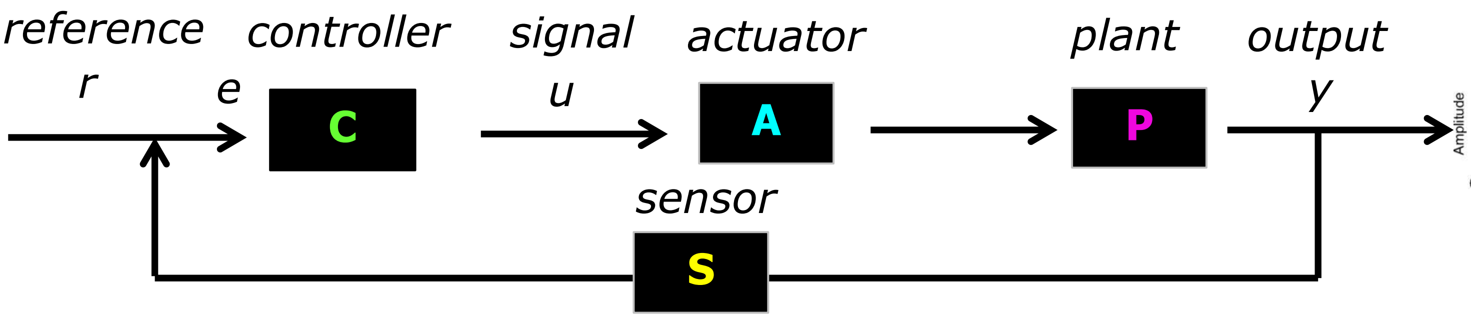
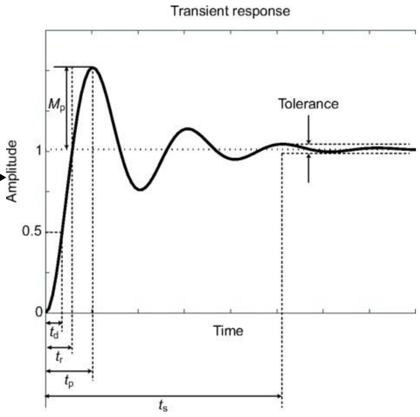
Contents

- Introduction to Control System
- Overview of control capabilities in LS-DYNA
- Control design toolbox in LS-DYNA
- *CTRLLER_PLANT: Model derivation
- PIDCTL and DELAY
- Piezoelectric material
- Next Steps

Introduction to Control System

- **Control**: process of making a system of design variables conform to some desired values



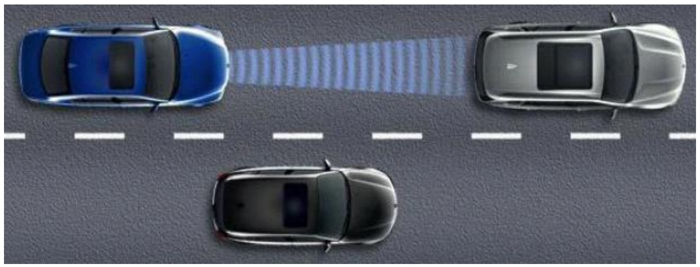


- **Reference**: the desired output
- **Sensor**: provides measurement of output
- **Actuator:** converts the control signal to power signal
- **Plant:** the physical part to be controlled, can be in the form of a linear system (represented as a transfer function or state space), or FEA model

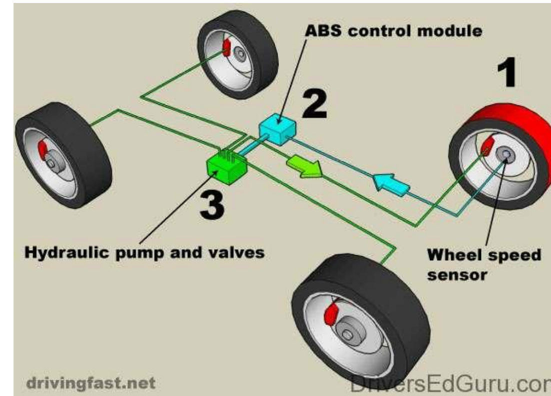
Introduction to Control System

Control in your daily life

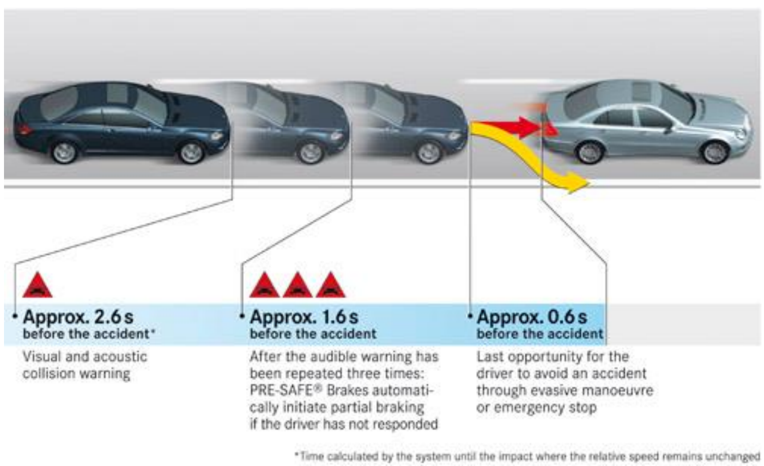
- Cruise control



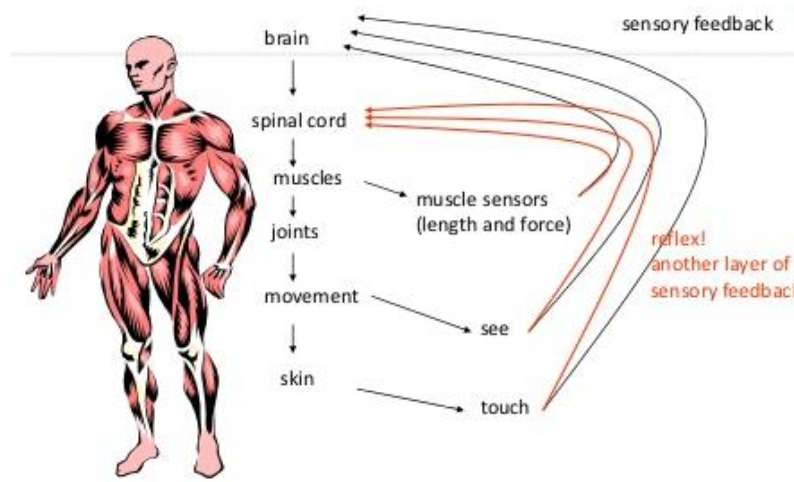
- ABS control



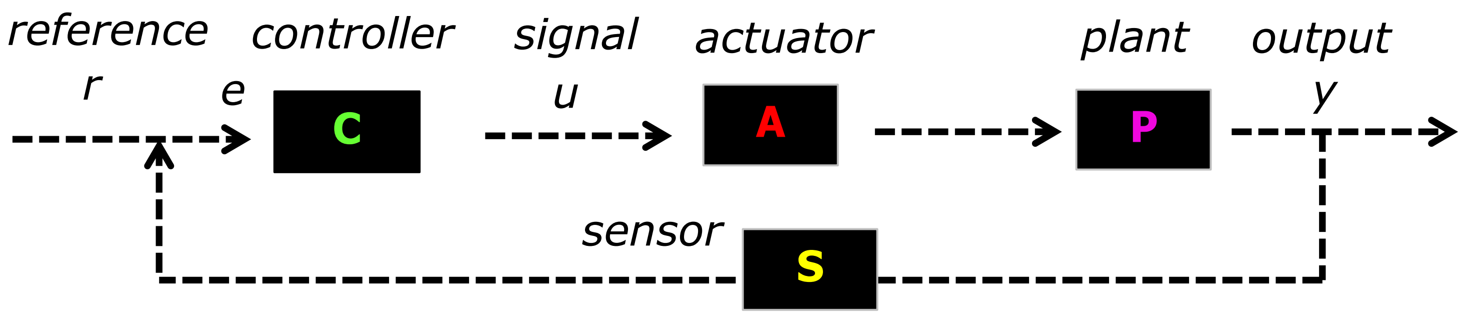
- Pre-crash system



- Human closed-loop system



Overview of Control Capabilities in LS-DYNA



- *CTRLLER keywords toolbox for controller design
- Controller GUI: under development
- *CTRLLER_PLANT for plant model derivation based on modes truncation method
- PIDCTL and DELAY in *DEFINE_CURVE_FUNCTION for control force application
- *MAT_PZELECTRIC for piezoelectric material-based sensor and actuator
- *SENSOR

Development status: **Just started** | | **To be tested** | | **done**

Control design toolbox in LS-DYNA

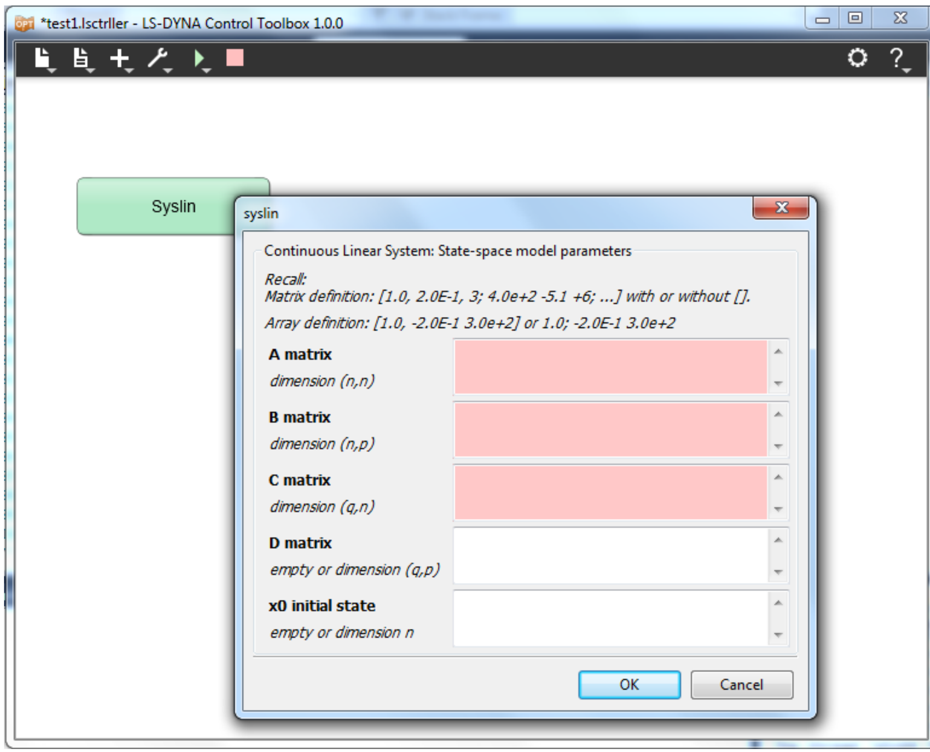
*CTRLLER keywords

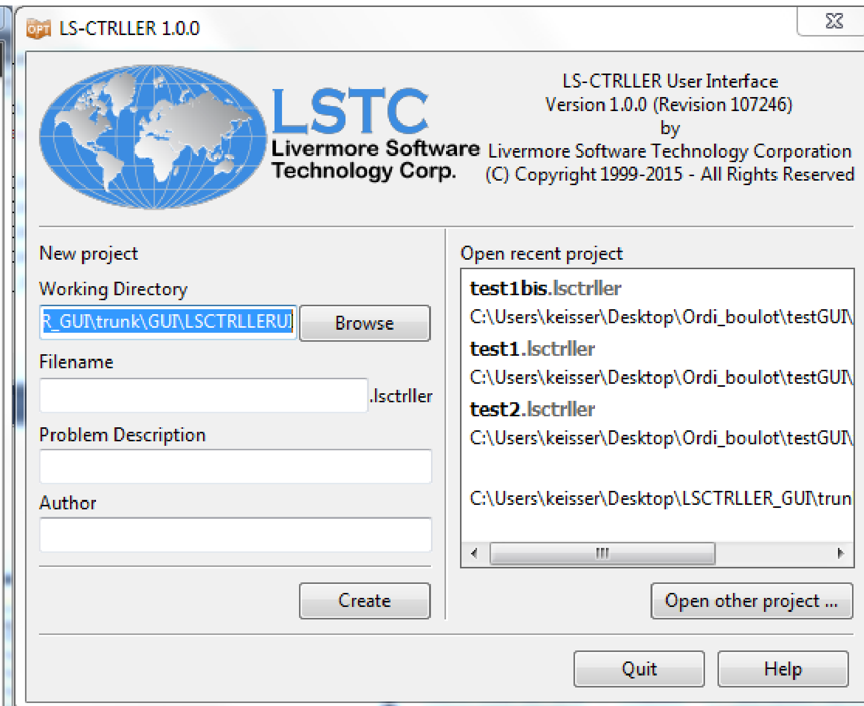
- System definition
  - *CTRLLER_ SYSLIN, TF, etc.
- Analysis
  - *CTRLLER_ RANK, ROOTS, SVD, EIG, PLZR, etc.
- Solver
  - *CTRLLER_ LSQ, ODE, CSIM, etc.
- Control tools
  - *CTRLLER_ PID, LQR, LQG, KALMAN, etc.
- Model Reduction
  - *CTRLLER_ BALANCMR, MINREAL, etc.
- System connections
  - *CTRLLER_FEEDBACK, etc.

Control design toolbox in LS-DYNA

Graphical User Interface

- Currently available: System definition
- Next focus: control tools, system connections, running ls-dyna solver, model reduction and analysis
- Long term focus: graphical result viewing





*CTRLLER_PLANT: Model derivation

P

*CTRLLER_PLANT

- A modes-reduction method for model order reduction (MOR)

$$M\ddot{d} + C\dot{d} + Kd = F \quad \Longrightarrow \quad \begin{aligned} \dot{x}(t) &= Ax(t) + Bv(t) \\ y(t) &= Cx(t) + Du(t) \end{aligned}$$

State equation

Output equation

ID, I/O & Freq. modes

Card 1	1	2	3	4	5	6	7	8
Variable	PLNTID	NINPUT	NOUTPUT	NMODE				

Output files

Card 2	1	2	3	4	5	6	7	8
Variable	FSCILAB		FLSDYNA		FMATLAB			

Input nodes & DOF

INPUT	1	2	3	4	5	6	7	8
Variable	IN1	IDOF1	IN2	IDOF2	IN3	IDOF3	IN4	IDOF4

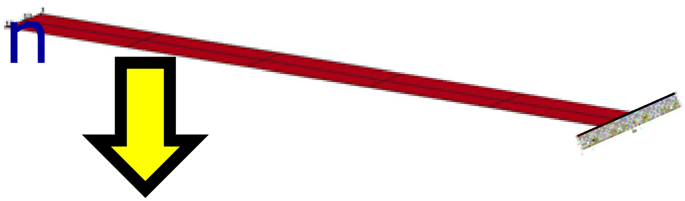
Output nodes & DOF

OUTPUT	1	2	3	4	5	6	7	8
Variable	ON1	ODOF1	ON2	ODOF2	ON3	ODOF3	ON4	ODOF4

Modes

Modes	1	2	3	4	5	6	7	8
Variable	mode1	mode2	mode3	mode4	mode5	mode6	mode7	mode8

*CTRLLER_PLANT: Model derivation example: Vertical vibration



Matrix A

a =

0.	0.	0.	0.	0.	1.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	1.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	1.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	1.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	1.
- 12774.	0.0000002	- 6.881D-08	0.0000002	5.576D-08	0.	0.	0.	0.	0.
0.0000002	- 460440.	0.0000001	0.0000002	- 6.525D-08	0.	0.	0.	0.	0.
9.658D-08	1.201D-08	- 3359300.	0.0000001	- 0.0000003	0.	0.	0.	0.	0.
0.0000001	0.0000002	- 0.0000002	- 11739000.	5.851D-08	0.	0.	0.	0.	0.
- 1.626D-08	- 4.630D-09	- 0.0000003	1.472D-08	- 25154000.	0.	0.	0.	0.	0.

Matrix C

c =

166.	149.56	118.58	74.446	- 31.458	0.	0.	0.	0.	0.
166.	149.6	118.93	75.458	- 32.592	0.	0.	0.	0.	0.
166.	149.56	118.58	74.446	- 31.458	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	166.	149.56	118.58	74.446	- 31.458
0.	0.	0.	0.	0.	166.	149.6	118.93	75.458	- 32.592
0.	0.	0.	0.	0.	166.	149.56	118.58	74.446	- 31.458

Matrix B

b =

0.	0.
0.	0.
0.	0.
0.	0.
0.	0.
- 166.	- 166.
149.56	149.56
- 118.58	- 118.58
- 74.446	- 74.446
- 31.458	- 31.458

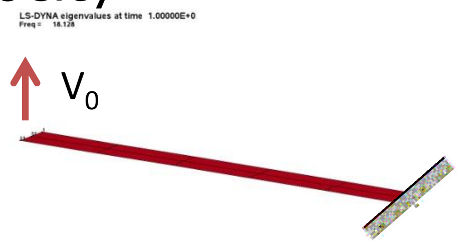
LSTC Livermore Software Technology Corp.

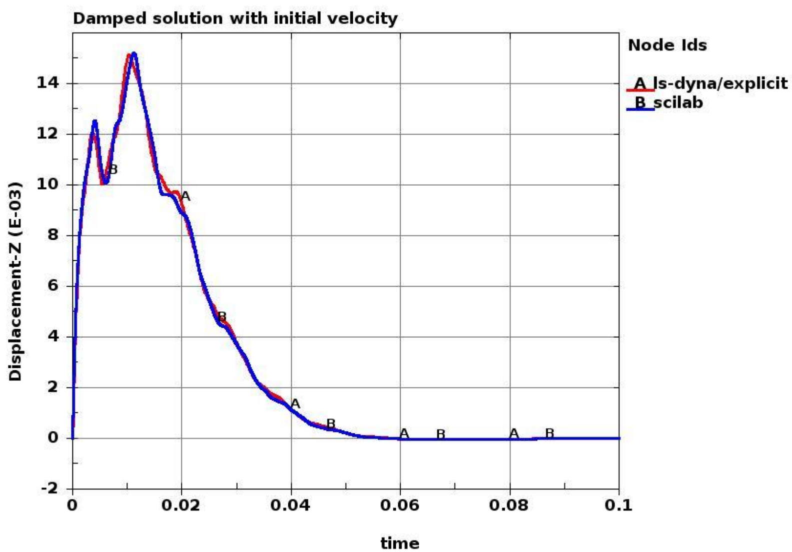
DYNA MORE

*CTRLLER_PLANT: Model derivation example: Vertical vibration

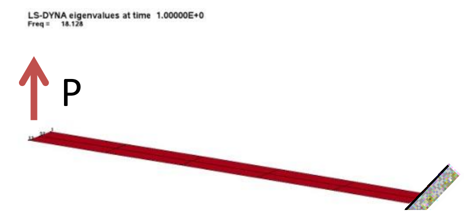
Validation of derived plant model:

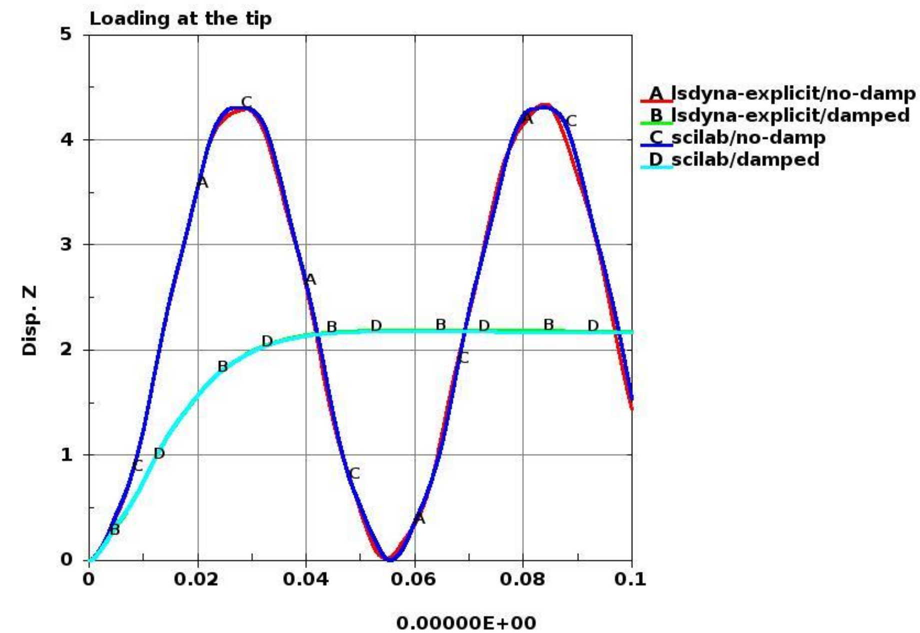
- Damped solution with initial vertical velocity





- Solution with initial step-loading

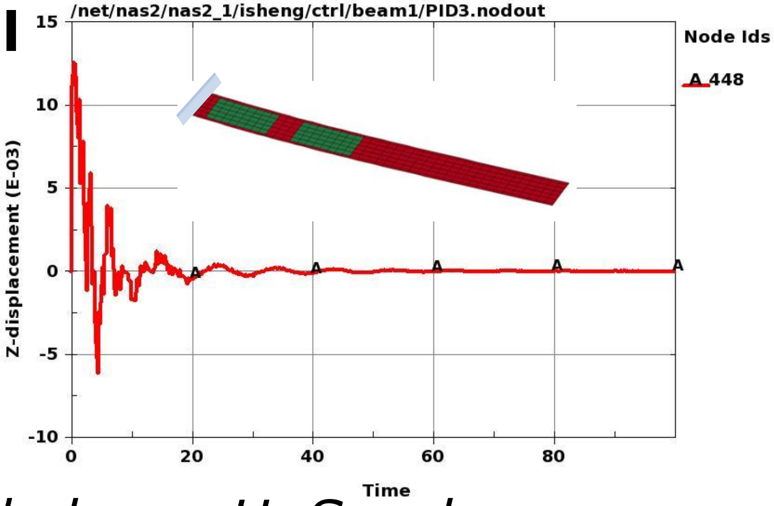




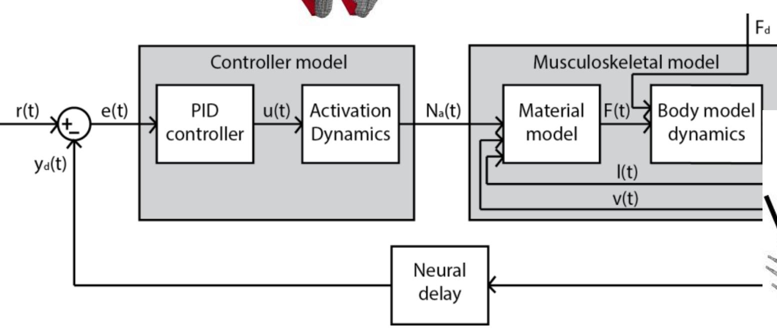
PIDCTL and DELAY

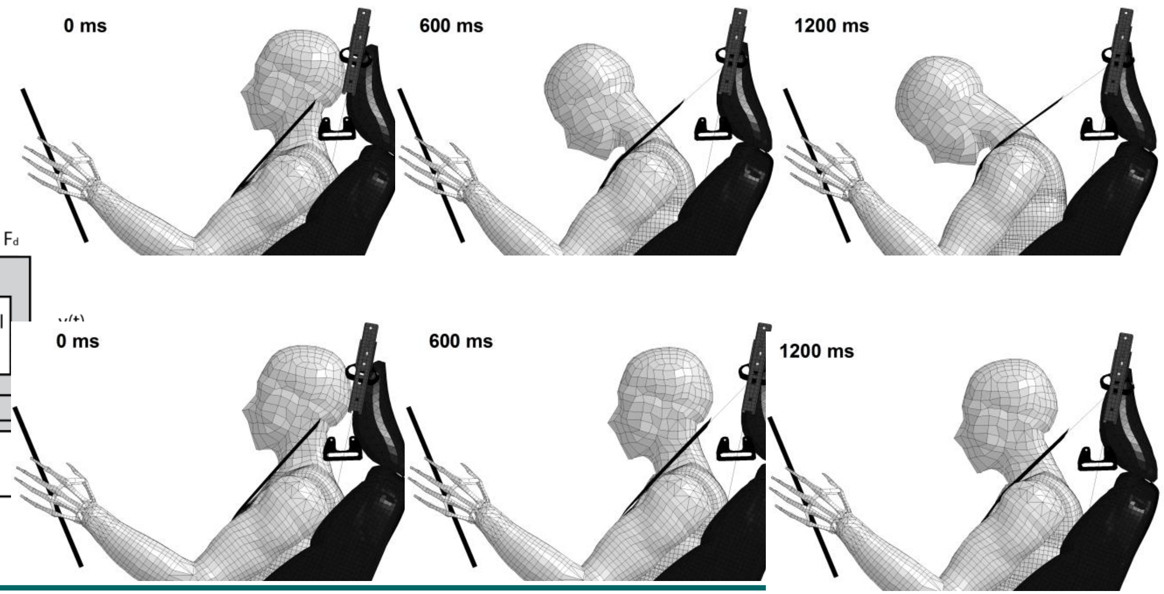
Vibration Control

```
*DEFINE_CURVE_FUNCTION
$#    lcid      sidr       sfa       sfo      offa      offo    dattyp
       201         0  1.000000  1.000000     0.000     0.000         0
DRX(1)
*DEFINE_CURVE_FUNCTION
$#    lcid      sidr       sfa       sfo      offa      offo    dattyp
         1         0  1.000000  1.000000     0.000     0.000         0
PIDCTL(101,  0.,0,  14.273400,0,0.,0,    3.31570,0,0.0,0,0.0)+
PIDCTL(102,  0.,0,  -0.951E+01,0,0.,0,   -0.01200,0,0.0,0,0.0)+
PIDCTL(201,  0.,0,  -42.910800,0,0.,0,   -0.51480,0,0.0,0,0.0)+
PIDCTL(202,  0.,0,  367.32540,0,0.,0,     3.6699,0,0.0,0,0.0)
```



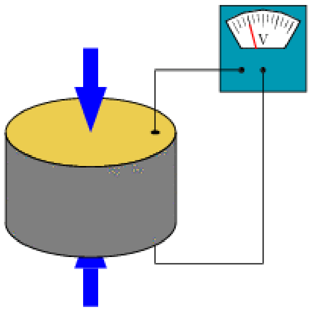
Active Muscle for HBM *by Chalmers U. Sweden*





Piezoelectric Material

- *Piezoelectric effects:*
  - *Direct*, sensor: generates electric potential when subject to mechanical stress.
  - *Inverse*, actuator: Application of an electric field (voltage) results in mechanical strain.



Sensor for wheel pressure

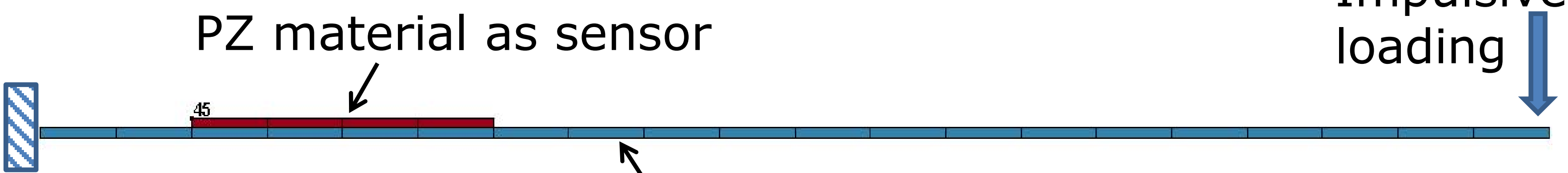
$$[\sigma] = [c^E][\varepsilon] - [e]^T\mathbf{E}$$

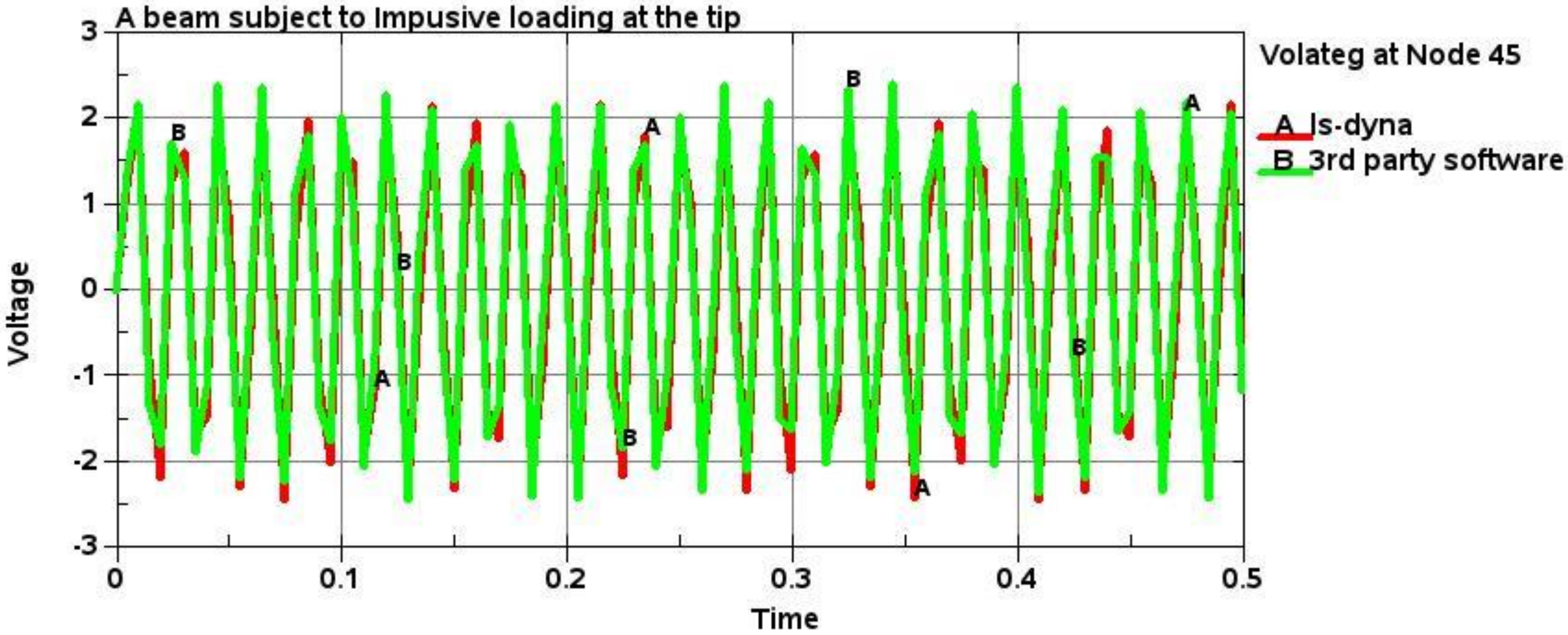
$$\mathbf{D} = [e][\varepsilon] + [d^S]\mathbf{E}$$

- LS-DYNA
  - *MAT_ADD_PZELECTRIC for PZ coefficients and dielectric coefficients
  - *BOUNDARY_PZEPOT for electric potential specification

Piezoelectric Material

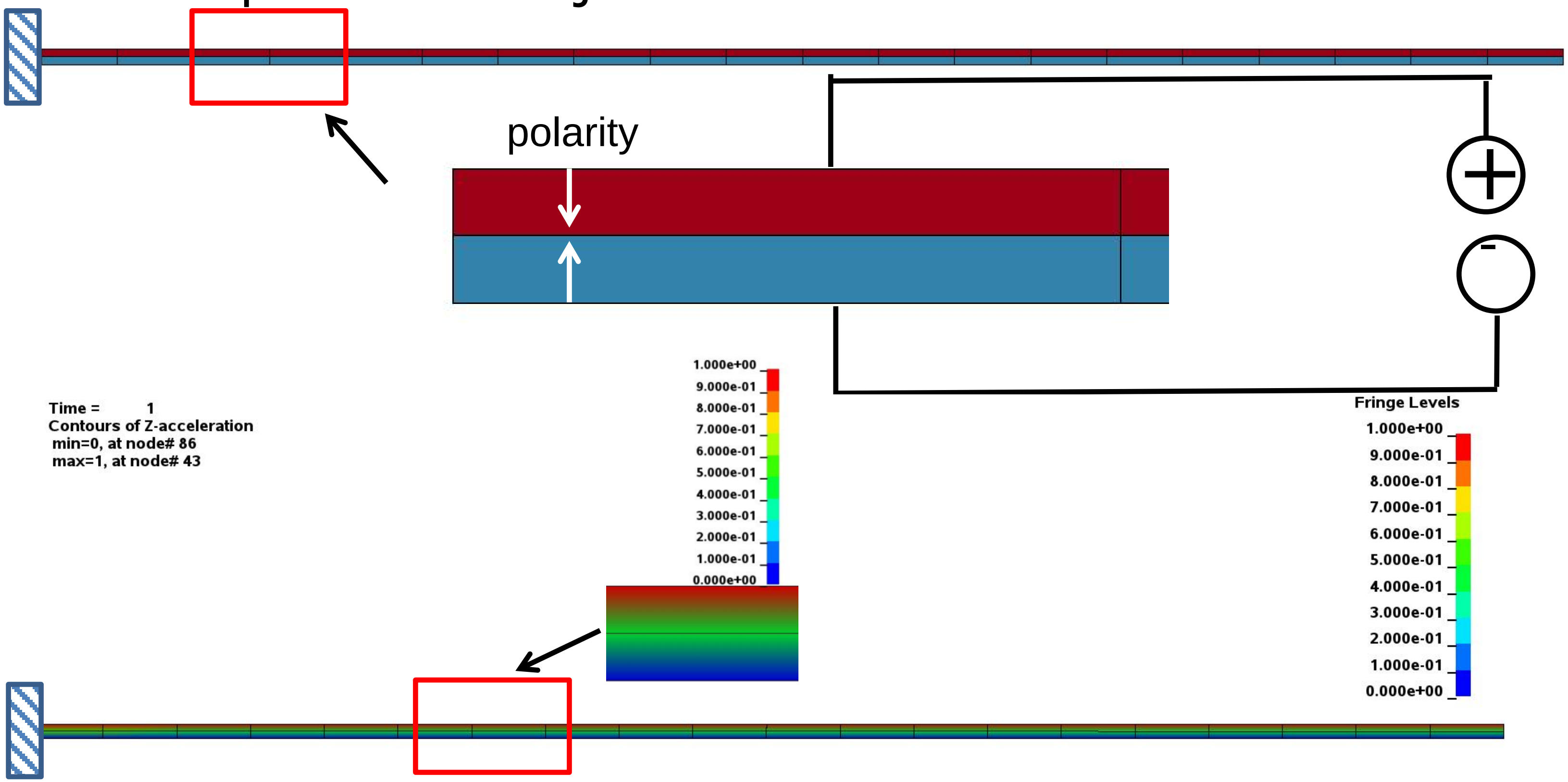
Validation of direction effect, sensor





Validation of inverse effect, actuator

- Bimorph beam subject to 1-V across the thickness



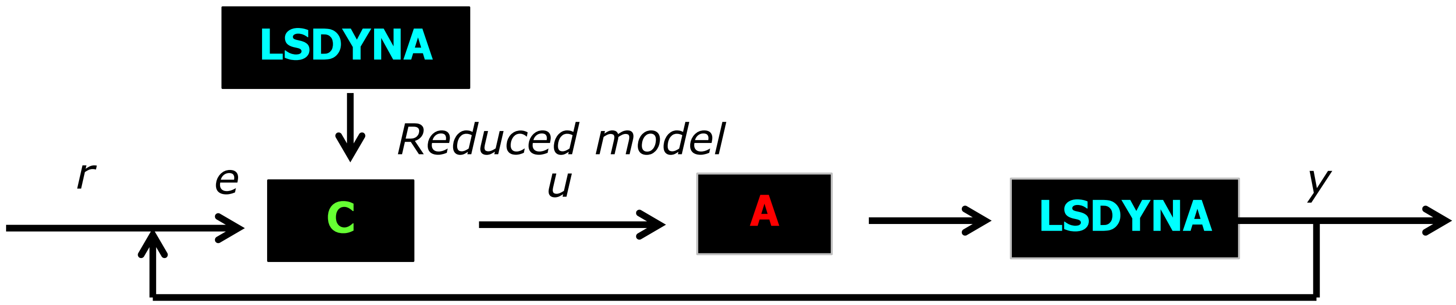
Voltage distribution

Tip displacement:

LS-DYNA: 3.33 e-7 vs. theoretical Sol. of 3.43 e-7

Next Steps

- *Achieve in two years*



  - Gather opinions from potential users
  - Improve currently implemented capabilities with more testing
  - More applications like MBS control, vibration control and acoustic control with piezoelectric material
  - More FEM model reduction methods and applications
- *Thanks to*
  - Katharina Witowski for helping in GUI implementation
  - François-Henri Rouet and Cleve Ashcraft for mathematical consultations
  - Zhidong Han for enhancing PIDCTL implementation

Thank you for your attention