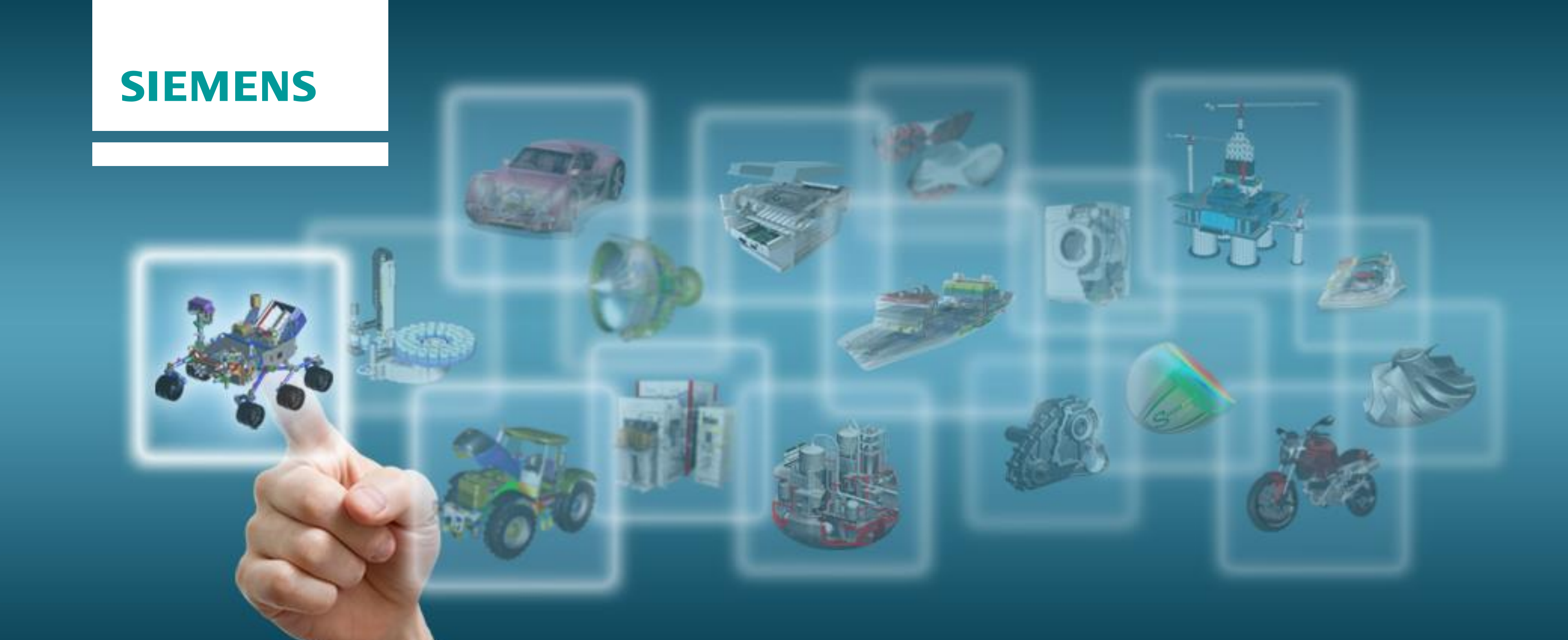
SIEMENS



ARRAYCON

Piezo modeling

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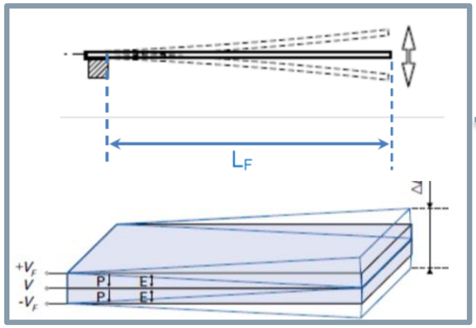
Realize Innovation.

Piezo modeling

Project context:



Complexity about piezo actuators/sensors:

- Multiple layers of piezo crystals, electrodes
- boundary conditions
- Numerical modeling is always simplified

Characterize the actuators/sensors properties:

- Can be used in the projects

Objectives of piezo modelling:

a) Numerical modeling of piezo actuator
b) Validation with experiment

Tasks:

1. Detail model in SAMCEF (layers and electrodes)
2. Benchmark against 1D (Beam model)
3. Execute experimental campaign (single clamped-free actuator)
   - With mechanical excitation
   - With electrical excitation
4. Comparison between simulation and experiments

Different modelling methods

Shell element modelling:

1. Uniform voltage on each piezo-layer
2. Two layer composite shell behavior in Samcef
3. Two electrical nodes (one for each piezo-layer)

Solid element modelling:

1. Uniform voltage on each piezo-layer
2. Two layer standard volume behavior in Samcef
3. Two electrical solid elements (The nodes of the electrical elements are linked with the electrodes which formed by the nodes on the structure)

Beam modelling:

1. Uniform voltage on each piezo-layer
2. Single Euler-Bernoulli beam model
3. Two tow piezo-layers

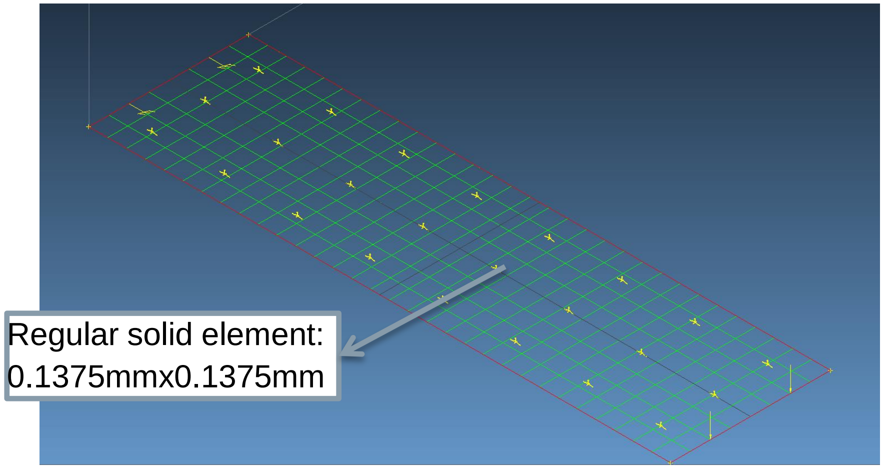
Plate modelling:

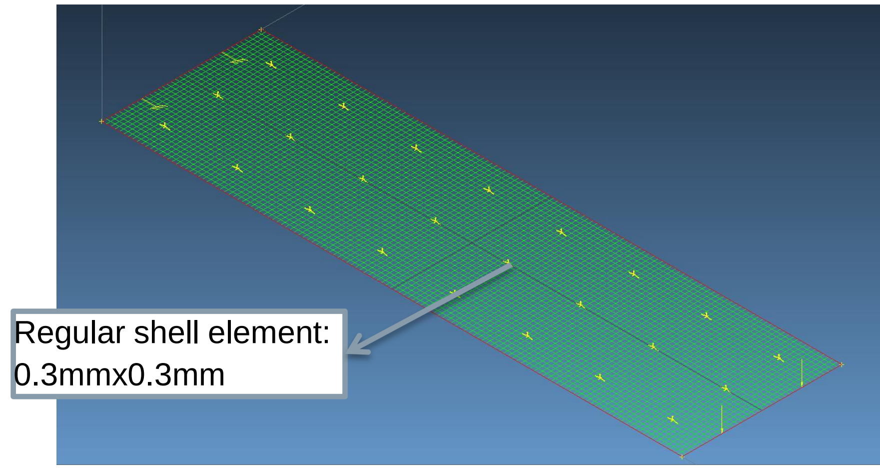
1. Uniform voltage on each piezo-layer
2. Single Kirchhoff plate model
3. Two piezo-layers

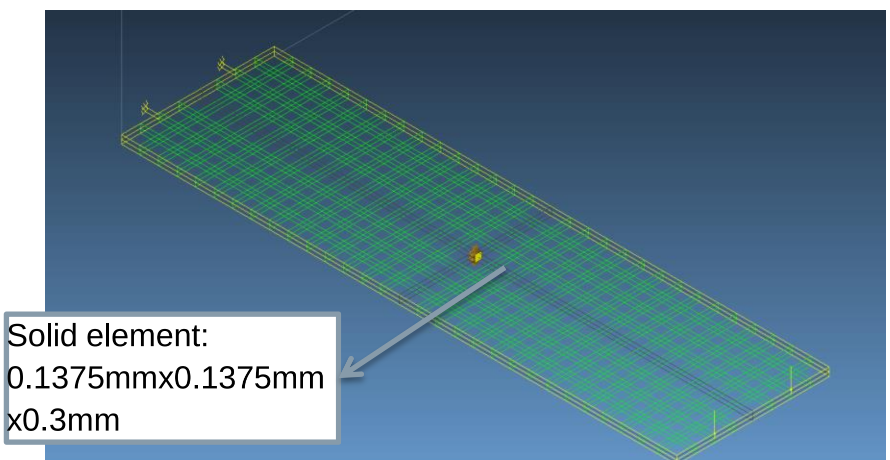
Rectangular section Beam/Plate	
Length	40 [mm]
width	11 [mm]
Thickness	0.6 [mm]
Poisson ratio	0.29
density	7954 [kg/m^3]

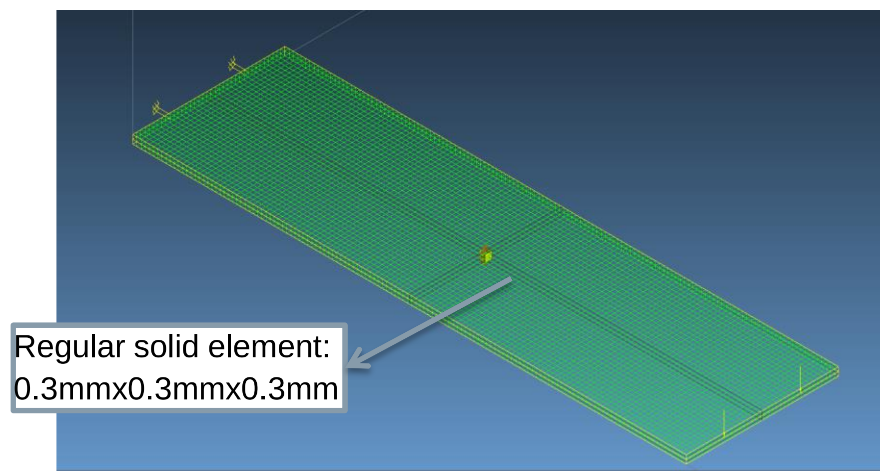
	PIC255/252
Physical and Dielectric Properties	
Density ρ [g/cm³]	7.80
Curie temperature T_c [°C]	350
Relative permittivity in the polarization direction $\varepsilon_{33}^T/\varepsilon_0$	1750
Perpendicular to the polarization $\varepsilon_{11}/\varepsilon_0$	1650
Dielectric loss factor tan δ [10^{-3}]	20
Electro-Mechanical Properties	
Piezoelectric deformation coefficient, piezo modulus*	
d_{31} [pm/V]	-180
d_{33} [pm/V]	400
d_{15} [pm/V]	550
Acousto-Mechanical Properties	
Elastic compliance coefficient	
s_{11}^E [10^{-12} m² /N]	16.1
s_{33}^E [10^{-12} m² /N]	20.7
Mechanical quality factor Q_m	80

Meshing refining in Samcef modelling





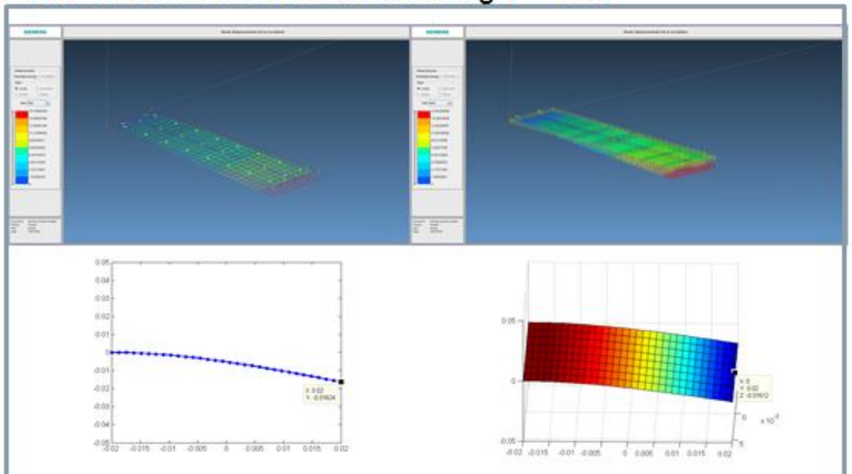




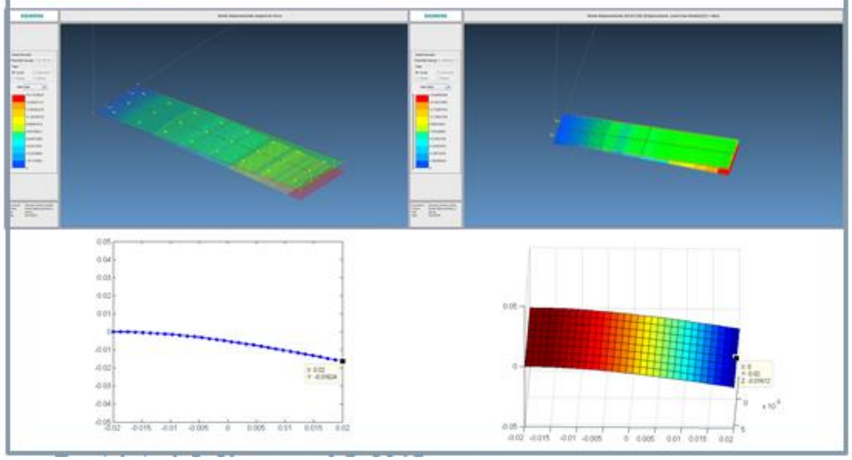
The meshes are standard in Matlab modellings: 1D 1.3mm and 2D 1.3mmx1.3mm

Modelling results

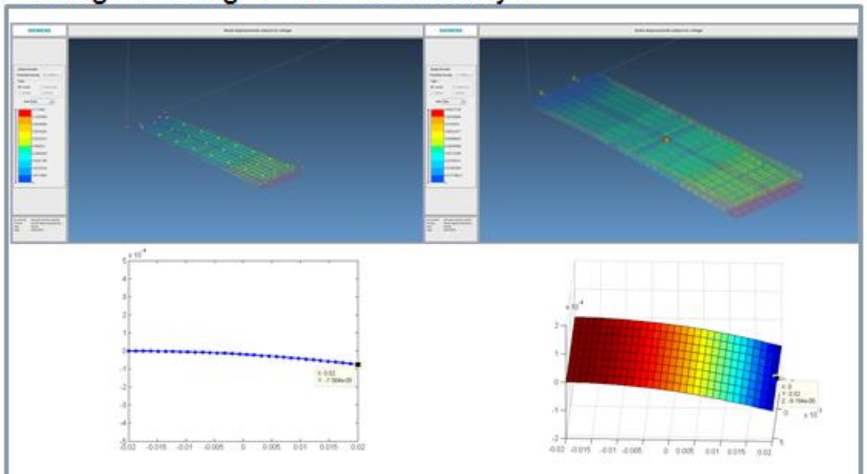
Piezoelectric effect static modeling F=-10N



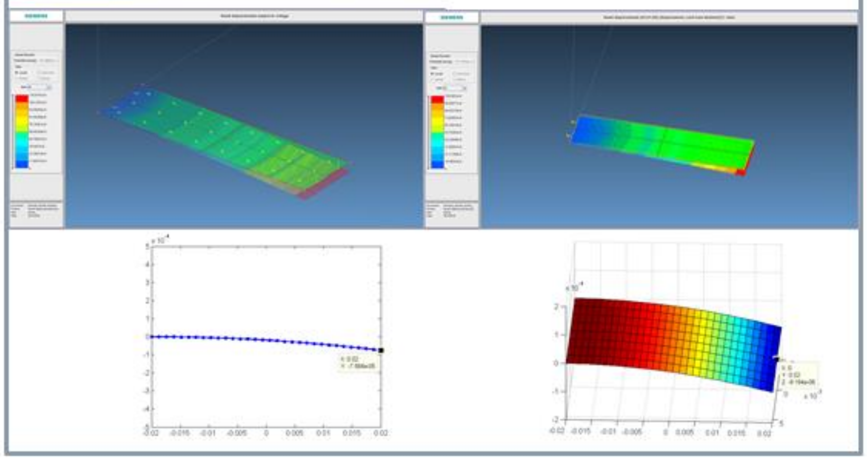
Samcef refined mesh Modelling:



Voltage bending V=30V on each layer



Samcef refined mesh Modelling:



Modelling results

Piezoelectric effect static modeling F=-10N

Simulation	Maxmum displacement [mm]	Error	
Samcef shell[1]	16.43	--	
Samcef solid[2]	16.18	--	
Matlab beam	16.24	-1.16%[1]	3.71%[2]
Matlab plate	16.16	-1.64%[1]	-1.24%[2]

Voltage bending V=30V on each layer

Simulation	Maxmum displacement [μm]	Error	
Samcef shell[1]	76.90	--	
Samcef solid[2]	61.96	--	
Matlab beam	75.84	-1.38%[1]	22.40%[2]
Matlab plate	71.41	-7.14%[1]	-7.14%[2]

Samcef refined mesh Modelling:

Simulation	Maxmum displacement [mm]	Error	
Samcef shell [1]	16.44	--	
Samcef solid [2]	16.27	--	
Matlab beam	16.24	-1.22%[1]	-0.18%[2]
Matlab plate	16.16	-1.70%[1]	-0.68%[2]

Simulation	Maxmum displacement [μm]	Error	
Samcef shell [1]	76.84	--	
Samcef solid [2]	70.07	--	
Matlab beam	75.84	-1.30%[1]	8.23%[2]
Matlab plate	71.41	-7.07%[1]	1.91%[2]

The Samcef modelling are considered as the reference for the error calculation.
[1] and [2] indicate different correspondent references

Modelling results

Piezoelectric effect static modeling F=-10N

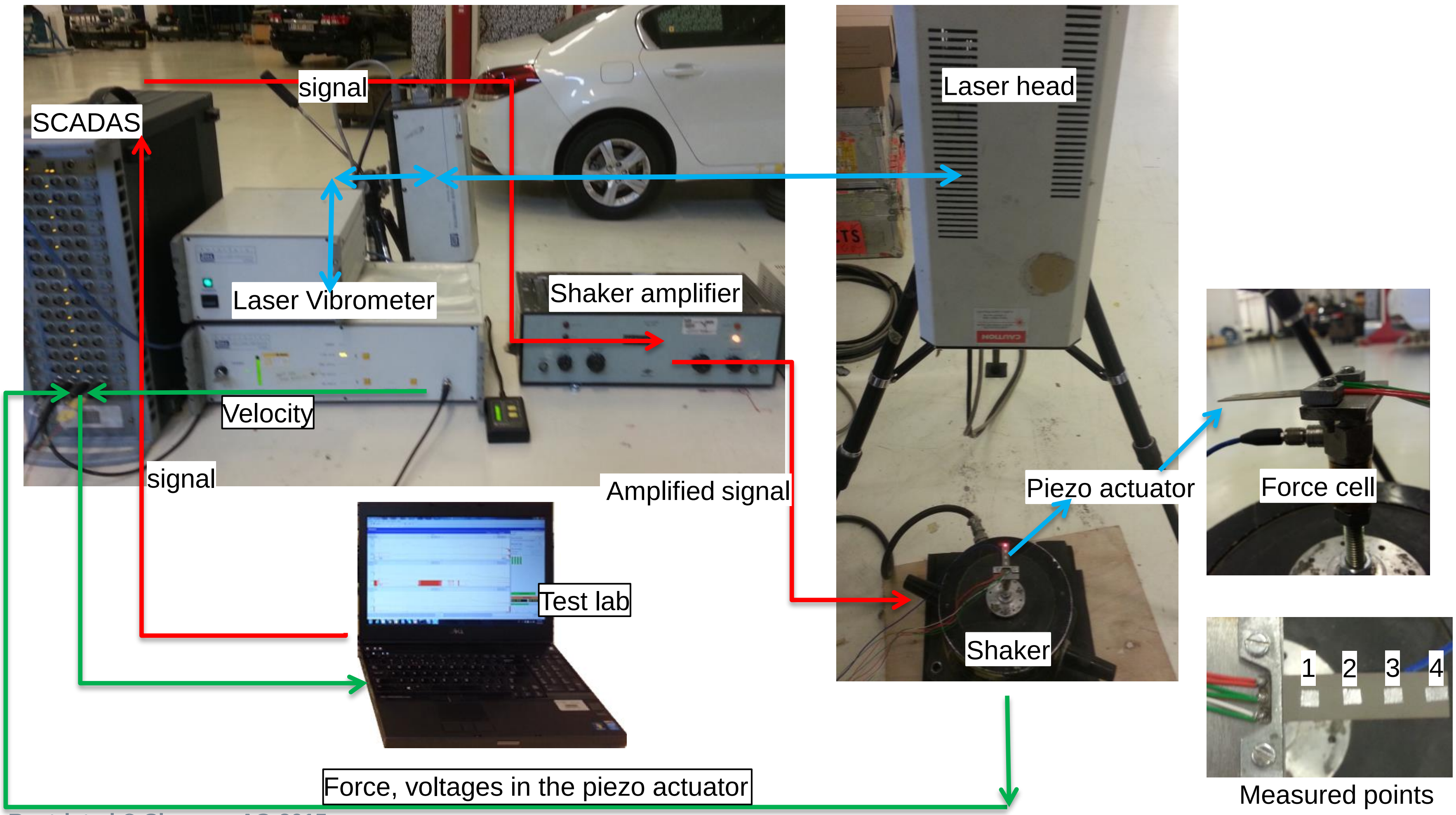
Simulation	Voltage on each piezo-layer [V]
Samcef shell	465.9
Samcef solid	334.6
Matlab beam	464.9
Matlab plate	446.0

Significant difference with other modellings

- The voltage does not receive any significant effect from the mesh size.
- The significant voltage difference comes from the simplification of the 1D and 2D modeling: the piezo constants are modified in the 1D and 2D modelling.

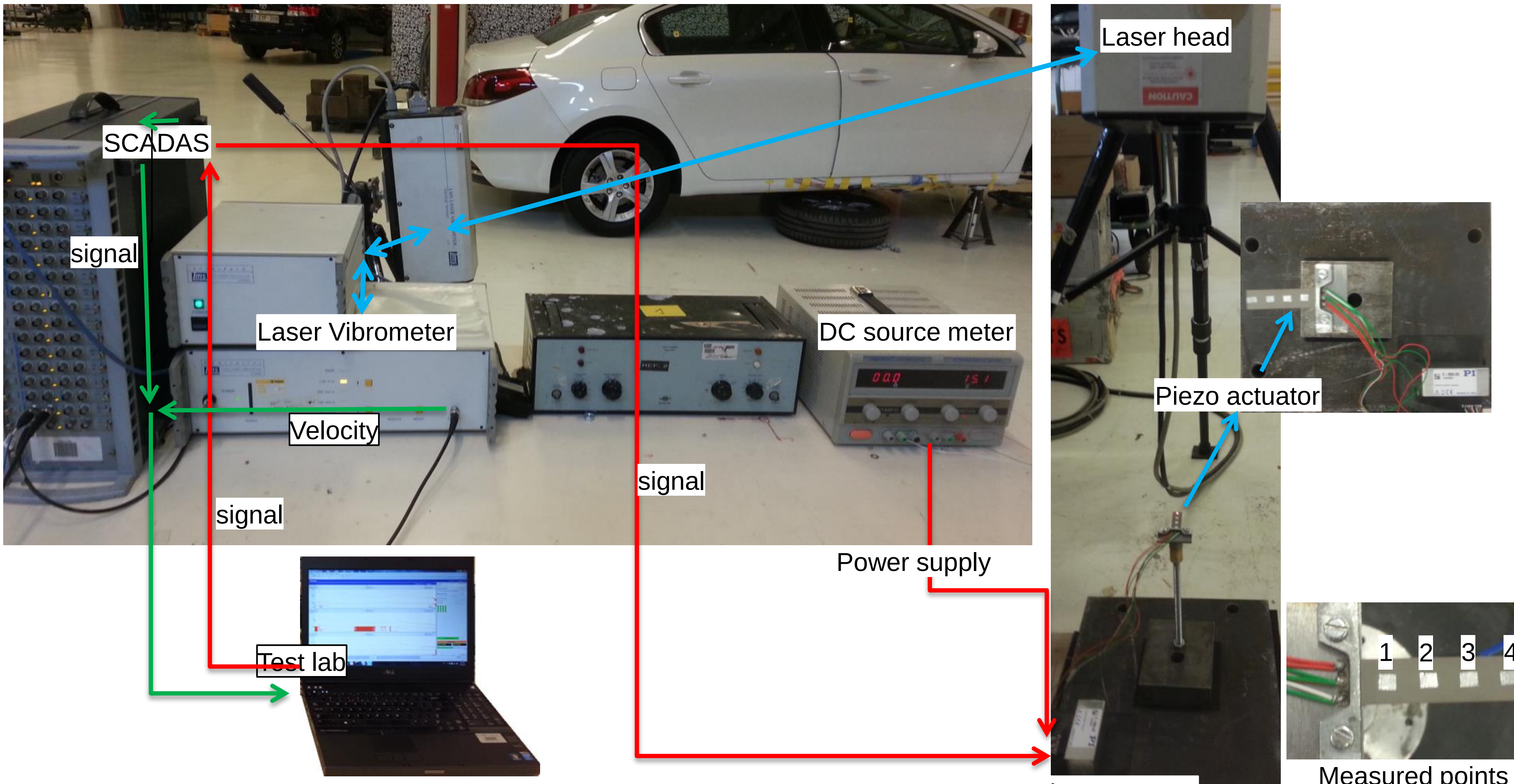
Experimental test setup

Mechanical excitation experimental test setup:



Experimental test setup

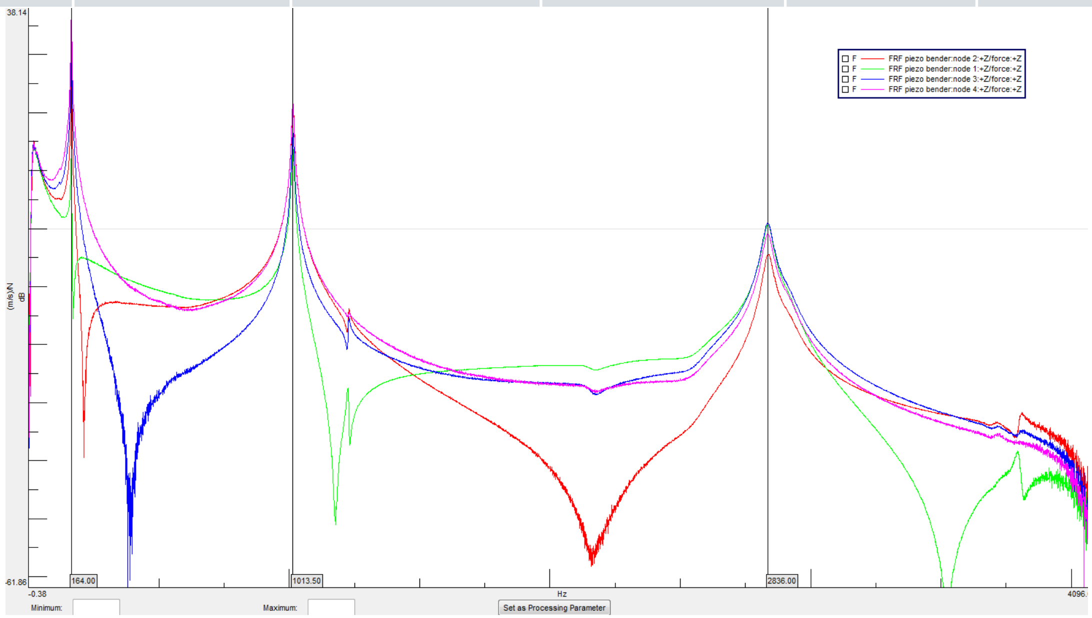
Electrical excitation experimental test setup:



Experimental results

Vibration testing of the bilayer bender

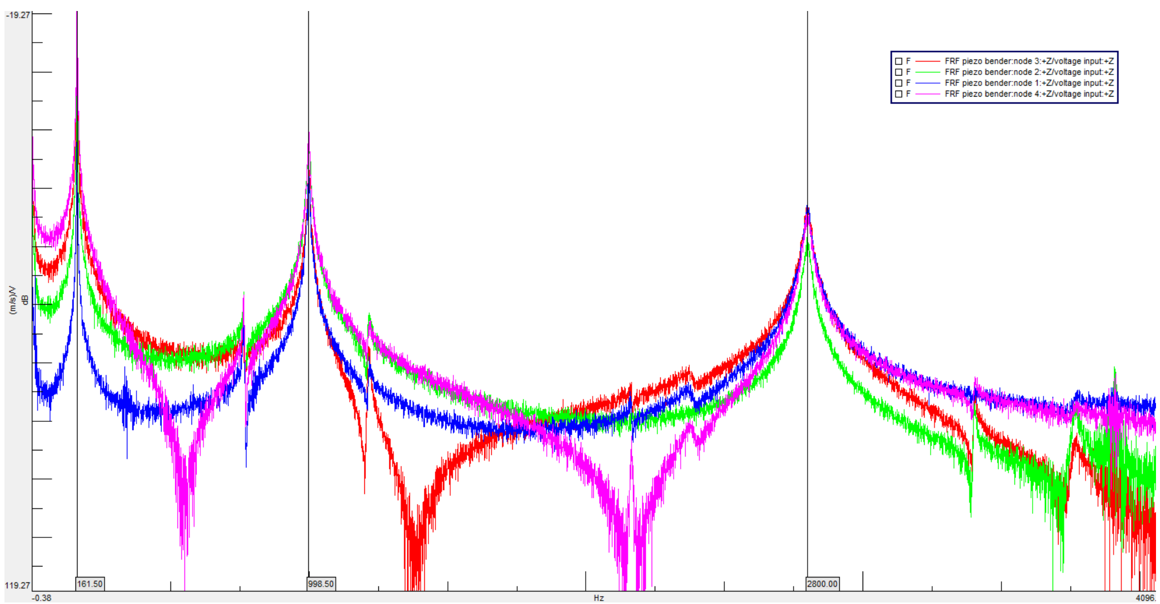
	Test Lab	Matlab beam modelling	Matlab plate modelling	From catalogue	Error between tests and Matlab modeling	
First natural frequency	163.8 Hz	173 Hz	175 Hz	160 Hz (+/- 20%)	5.6%	6.8%
Second natural frequency	1013.9 Hz	1057 Hz	1064 Hz	--	4.3%	4.9%
Third natural frequency	2835.8 Hz	2934 Hz	2978 Hz	--	3.5%	5.0%



Experimental results

Voltage excitation testing of the bilayer bender

	Test Lab	Matlab beam modelling	Matlab plate modelling	From catalogue	Error between tests and Matlab modeling	
First natural frequency	161.50 Hz	173 Hz	175 Hz	160 Hz (+/- 20%)	7.1%	8.4%
Second natural frequency	998.5 Hz	1057 Hz	1064 Hz	--	5.9%	6.6%
Third natural frequency	2799.1 Hz	2934 Hz	2978 Hz	--	4.8%	6.4%



Finding

1. Matlab beam modelling:

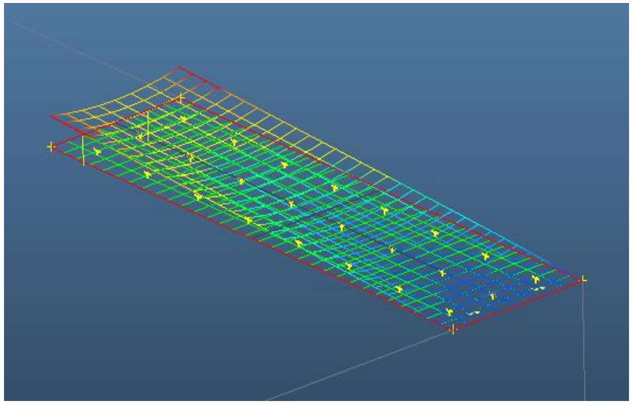
- Consider the effects of piezo-constants e_{32} & e_{33} into the modelling
- A single layer Euler-Bernouill beam model can be used to simulate multi-layer actuators.

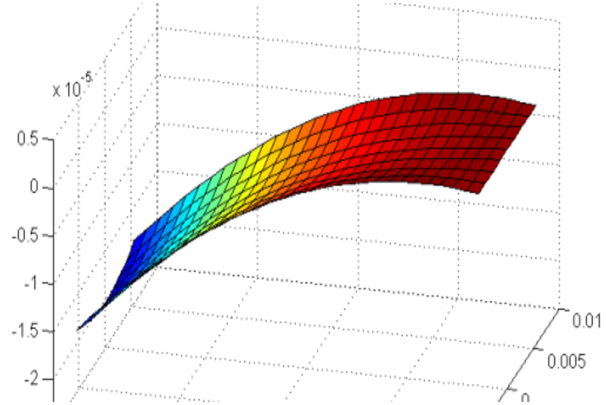
2. Matlab plate modelling

- Using the 2D piezoelectric constitute relation in the modelling
- The Poisson effect plays a role in the piezo modelling (slide 10).
- The modelling should be adopted to simulate multi-layer actuators to reach a good level accuracy.

Finding

Effect of the piezoelectric constant on the deflection of the bilayer bender ($e_{31} = 0$ & $e_{32} \neq 0$) in Samcef and Matlab modelling:





- Different longitudinal bending directions
- Create a 20% displacement difference (shows in slides 5 & 6) between Samcef and Matlab modelling (This longitudinal bending due to e_{32} reduce the bending due to e_{31})

This phenomena in Matlab modeling comes from the Poisson effect between longitudinal and transverse directions.

Conclusion

Conclusion on the numerical modeling:

1. Both Samcef shell and solide elememt modelling are working .
2. Matlab beam modelling shows a good agreement with Samcef shell modelling.
3. The natural frequencies from the Matlab modelling has an agreement with the experimental tests.

Ongoing steps:

1. Run more experiment tests of the bi-layer benders
2. Characterize the properties of the bi-layer bender
3. Validate the Numerical modeling by experiments