Study of Passive and Active Deformation Behaviors of Hybrid Specimens Made of Composite Substrates and MFC Piezoelectric Patches

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Outline

- Introduction
  - About the FutureWings project and its objectives
  - Some notes on hybrid specimens
- Numerical studies of bending and torsion of hybrid specimens
  - Finite element analyses of piezoelectricity
- Experimantal tests on hybrid specimens
  - Test equipment
  - Bending tests
  - Torsion tests
- Comparison between Numerical and Experimental Results

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Wings of the Future

"Think of an airplane as a great body with its end structures (wings, horizontal tail surfaces, vertical tail surfaces) that could have the possibility to change their shape as they had internal nerve endings and muscles ..."

"FutureWings" is an International Project co-financed by the European Union under the 7th Framework Program (1st June 2013 – 31th May 2015)

Wings of the Future

The FutureWings project focuses on the development of a wing structure having the capability of changing its aerodynamic shape (“self-shaping wing”) through the use of a new type of hybrid materials, made up of piezoelectric fibers drowned into composite materials.

For a morphing wing, traditional control surfaces (such as ailerons, flaps, slats and so on) are no longer required; that allows us to save weight in wing structures and reduce the sources of vibrations.

The deformed shape of a wing required by a given flight maneuver will be obtained as a result of medium/high voltages applied to the active piezo-electric layers.

Low electric power level and very small current intensity values should be require to deform the FutureWings structure.

SEVENTH FRAMEWORK PROGRAMME

Wings of the Future

The final goal of the FutureWings project is to manufacture a small scale model of the Future Wing.

This requires a proper design of the hybrid active composite laminate (composite layup, ply stacking sequence, piezo electric fibers orientation and so on), supported by testing activities and finite element non-linear analyses.

Mechanical tests on the Future Wing model will be carried out to verify the technical feasibilty of the FutureWings concept.

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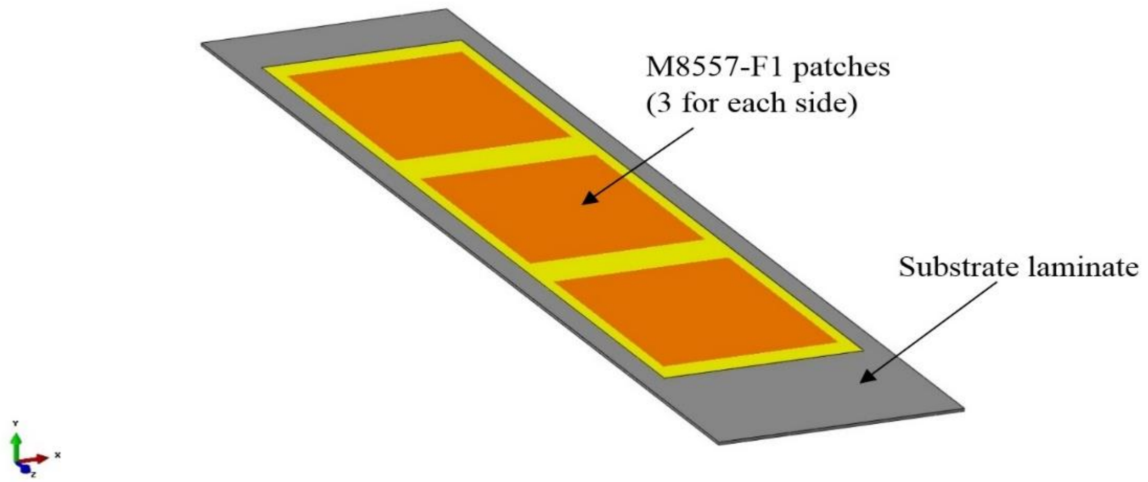
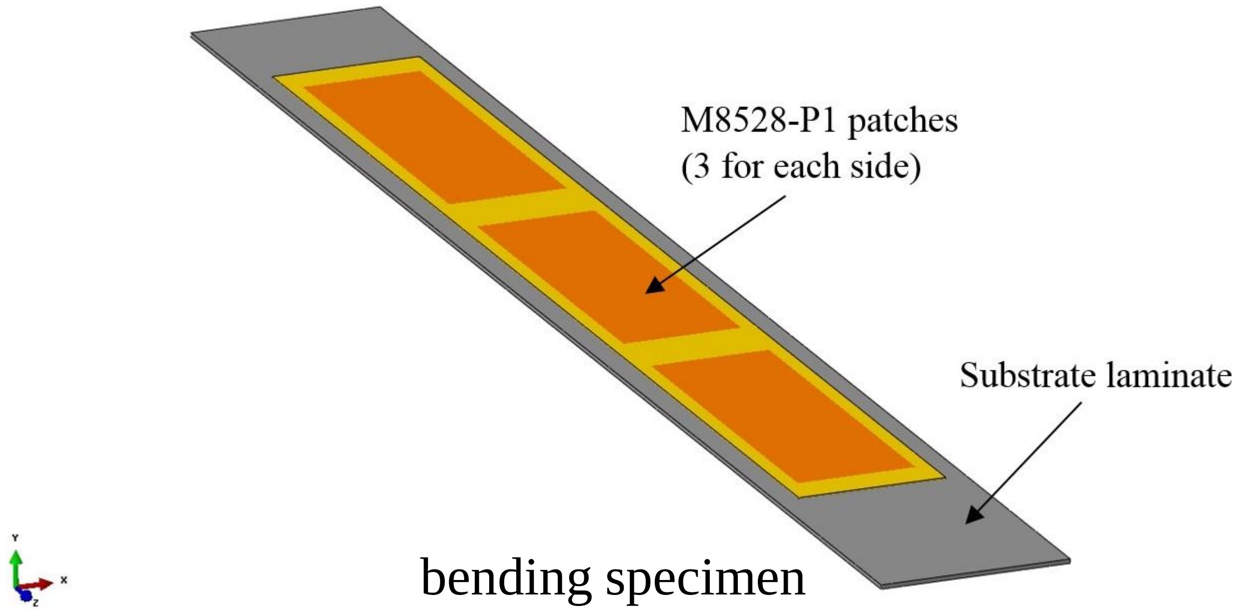
Hybrid Specimens

Until now, much effort into the project has been made at studying deformation behaviors of realistic hybrid specimens made of composite materials and Macro Fiber Composite (MFC) piezoelectric patches.

Two kinds of hybrid specimens have been considered



torsion specimen



bending specimen

Hybrid Specimens: Laminated substrate

For each kind of hybrid specimens, two types of laminated substrate have been considered:

- 4-ply Graphite/Epoxy laminate made of KGBX2508 0°/90° fabrics
- 4-ply Glass/epoxy laminate made of GGBX2808 0°/90° fabrics

Two ply stacking sequences have been chosen for the testing activities:

Ply Id	Sequence 1	Sequence 2
1	+45/-45	0/90
2	0/90	+45/-45
3	0/90	+45/-45
4	+45/-45	0/90

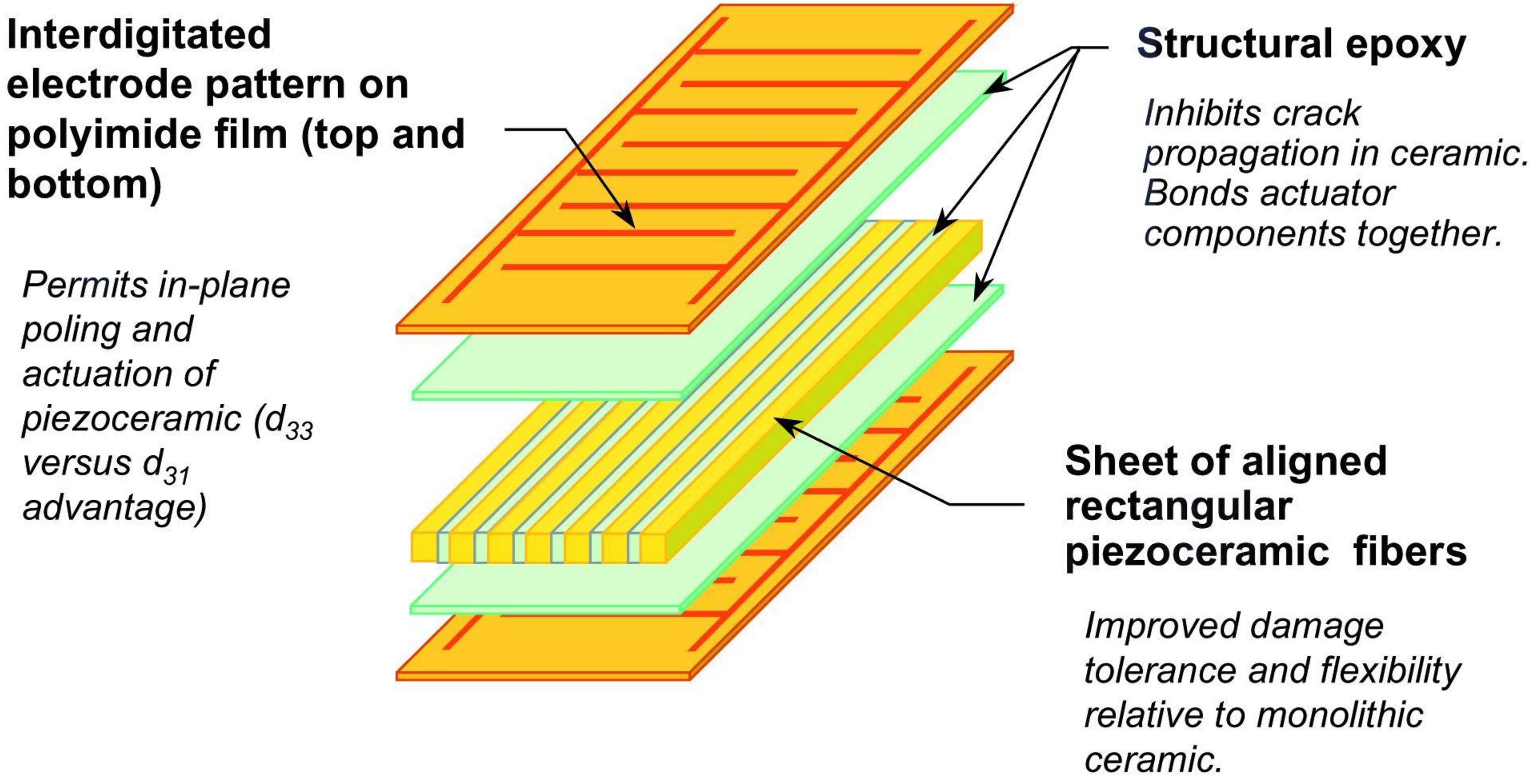
Mechanical properties of KGBX2508 and GGBX2808 fabrics have been obtained by means of material characterization tests.

Hybrid Specimens: Macro Fiber Composite (MFC)

What is a Macro Fiber Composite (MFC)?

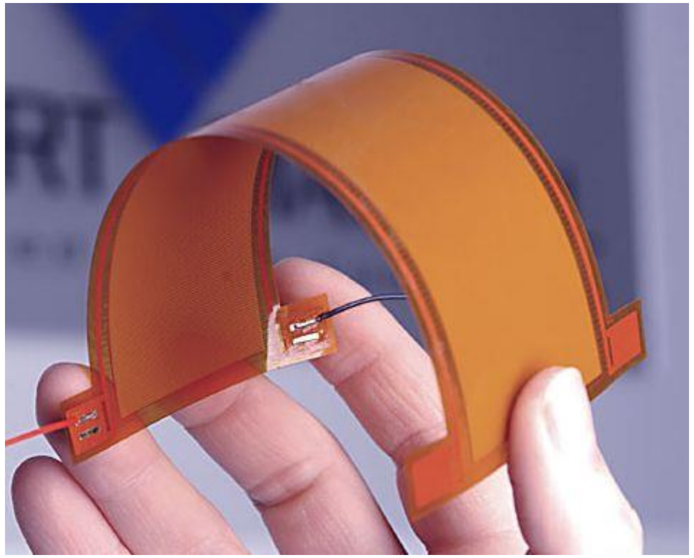
MFC benefits

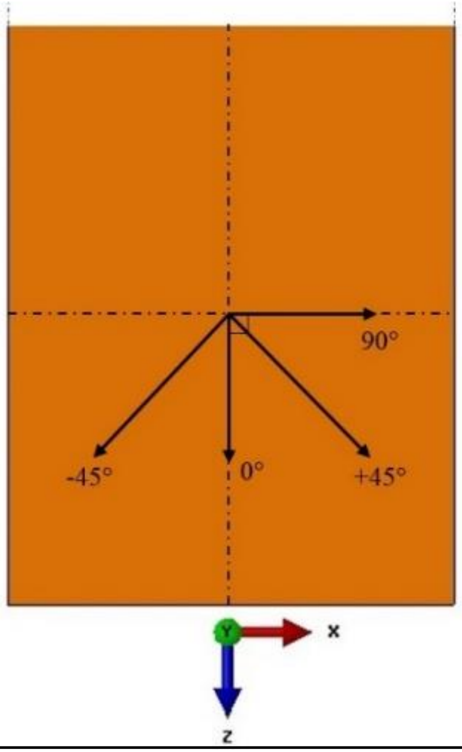
- Flexible and durable
- Increased strain actuator efficiency
- Directional actuation/sensing
- Damage tolerant
- Available as elongator (d33 mode) and contractor (d31 mode)
- Conforms to surfaces
- Readily embeddable
- Environmentally sealed package
- Demonstrated performance
- Different piezo ceramic materials available

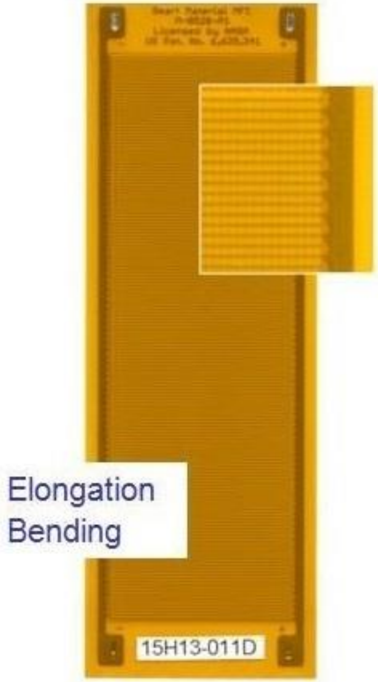


Hybrid Specimens: Macro Fiber Composite

MFC types and piezoelectric fiber orientation

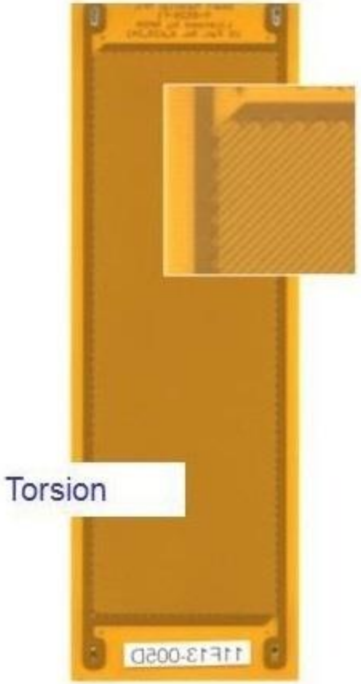






M8528-P1

- high strain (d33)
- -500V … 1500V
- 0° fiber orientation



M8528-F1 / M8557-F1

- high strain (d33)
- -500V … 1500V
- 45° fiber orientation

units in mm

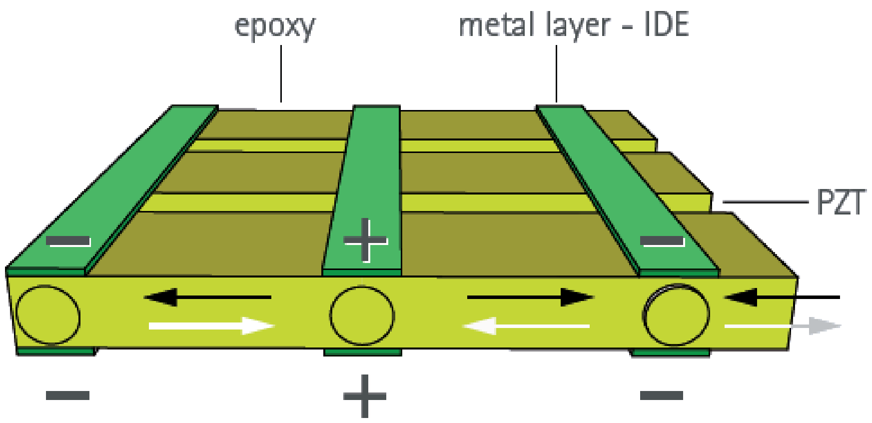
	Length	Width	Active length	Active width	thickness
MFC M8528-P1	103	35	85	28	0.3
MFC M8557-F1	105	65	85	57	

Hybrid Specimens: How a MFC works

Two operational modes:

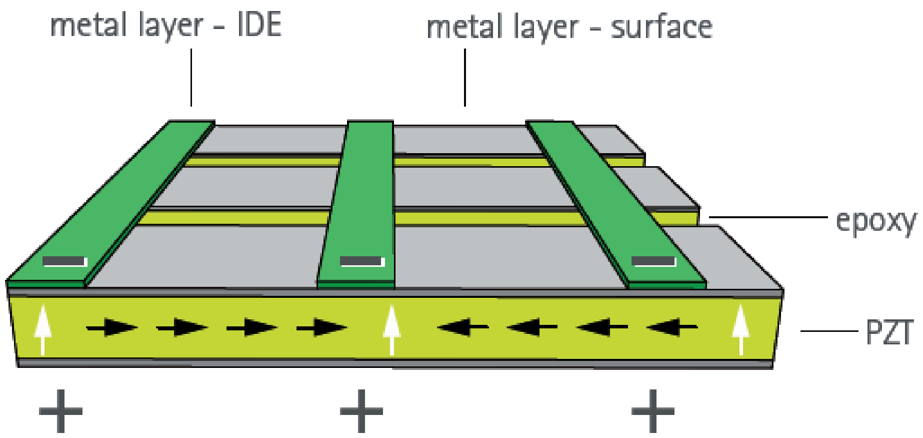
MFC P1 Type (d_{33} effect)

Elongator
- powerful actuator
- sensitive sensor



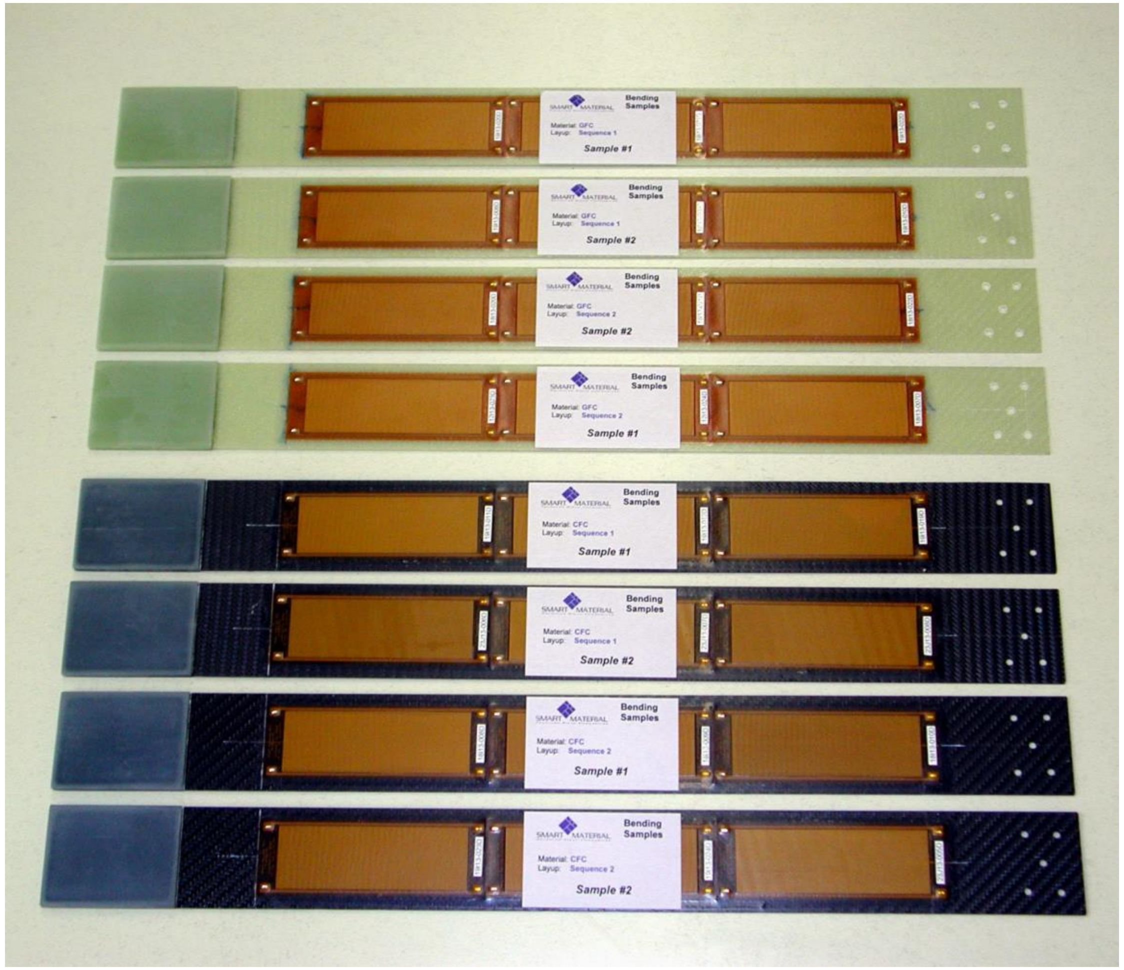
MFC P2 Type (d_{31} effect)

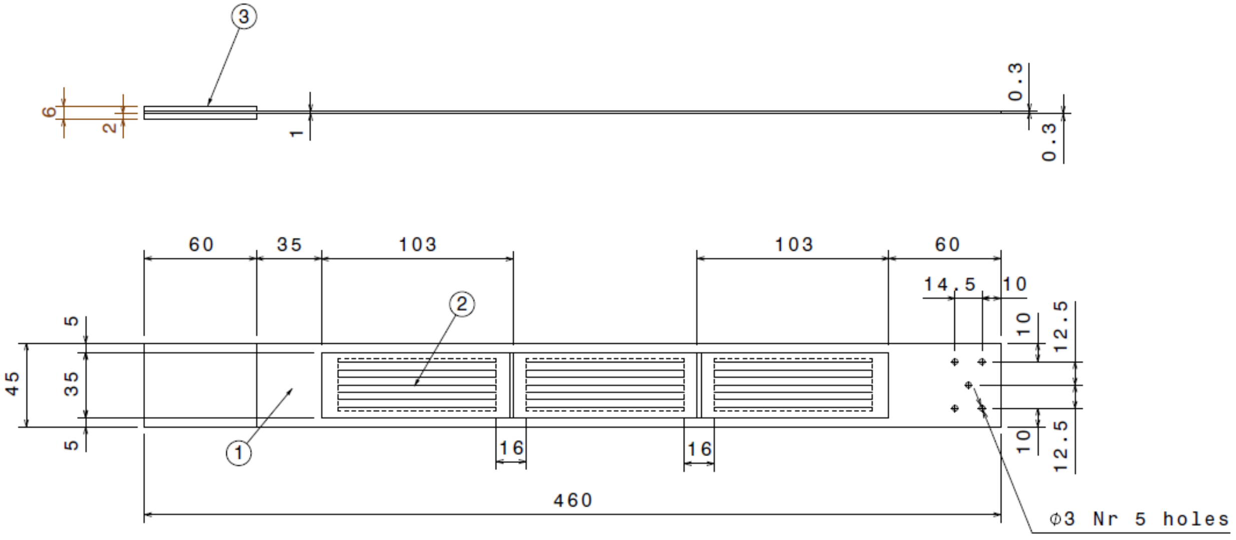
Contractor
- Low Impedance sensor
- energy generator



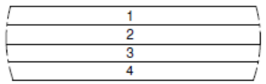
Hybrid Specimens: Manufacturing

Bending specimens





ply stacking sequence



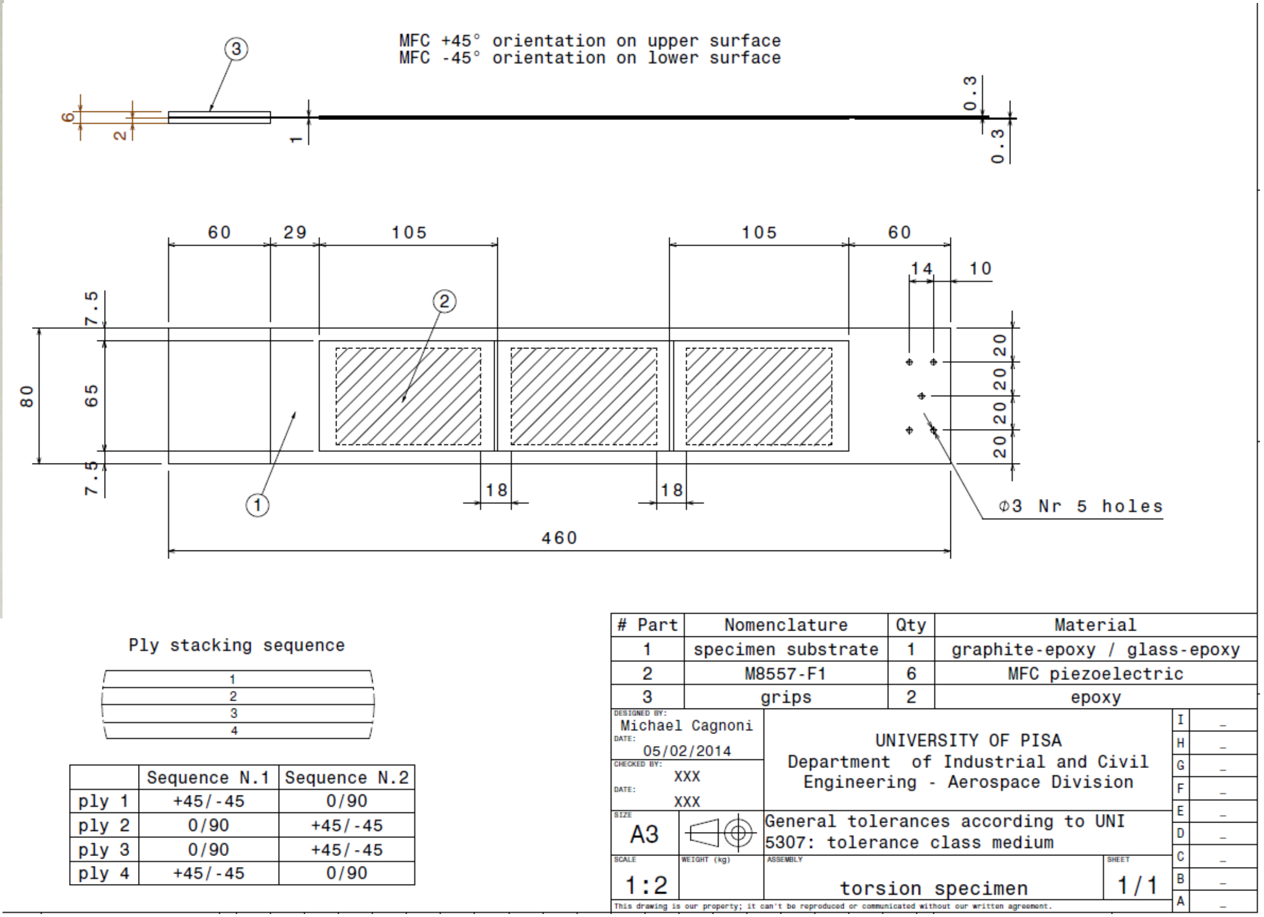
	Sequence N.1	Sequence N.2
ply 1	+45/-45	0/90
ply 2	0/90	+45/-45
ply 3	0/90	+45/-45
ply 4	+45/-45	0/90

# Part	Nomenclature	Qty	Material
1	specimen substrate	1	graphite-epoxy / glass-epoxy
2	M8528-P1	6	MFC piezoelectric
3	grips	2	epoxy

DESIGNED BY: Michael Cagnoni
DATE: 11/02/2014
CHECKED BY: XXX
DATE: XXX
UNIVERSITY OF PISA
Department of Industrial and Civil Engineering - Aerospace Division
SIZE A3
General tolerances according to UNI 5307: tolerance class medium
SCALE 1:2
WEIGHT (kg)
ASSEMBLY bending specimen
SHEET 1/1

Hybrid Specimens: Manufacturing

Torsion specimens



	Sample weigth [g]	
	Graphite/epoxy laminate	Glass/epoxy laminate
Bending sample	74	78
Torsion sample	137	147

Hybrid Specimens: Mechanical properties

Engineering constants	Graphite/epoxy substrate	Glass/epoxy substrate	Bonding resin	Kapton	MFC active area
E_1 [GPa]	67	25.3	4	2.5	30.34
E_2 [GPa]	67	25.3			15.86
E_3 [GPa]	67	25.3			15.86
ν_{12}	0.042	0.119	0.4	0.34	0.31
ν_{13}	0.042	0.119			0.16
ν_{23}	0.042	0.119			0.16
G_{12} [GPa]	4.78	4.83			5.51
G_{13} [GPa]	4.78	4.83			5.51
G_{23} [GPa]	4.78	4.83			5.51
Density [kg/m^3]	1852	2273	833.4	1320	5440
Dielectric [F/m]					ϵ_{ii} = 1.64E-08
Piezoelectric [m/V]					d_{31} = 4.6E-10

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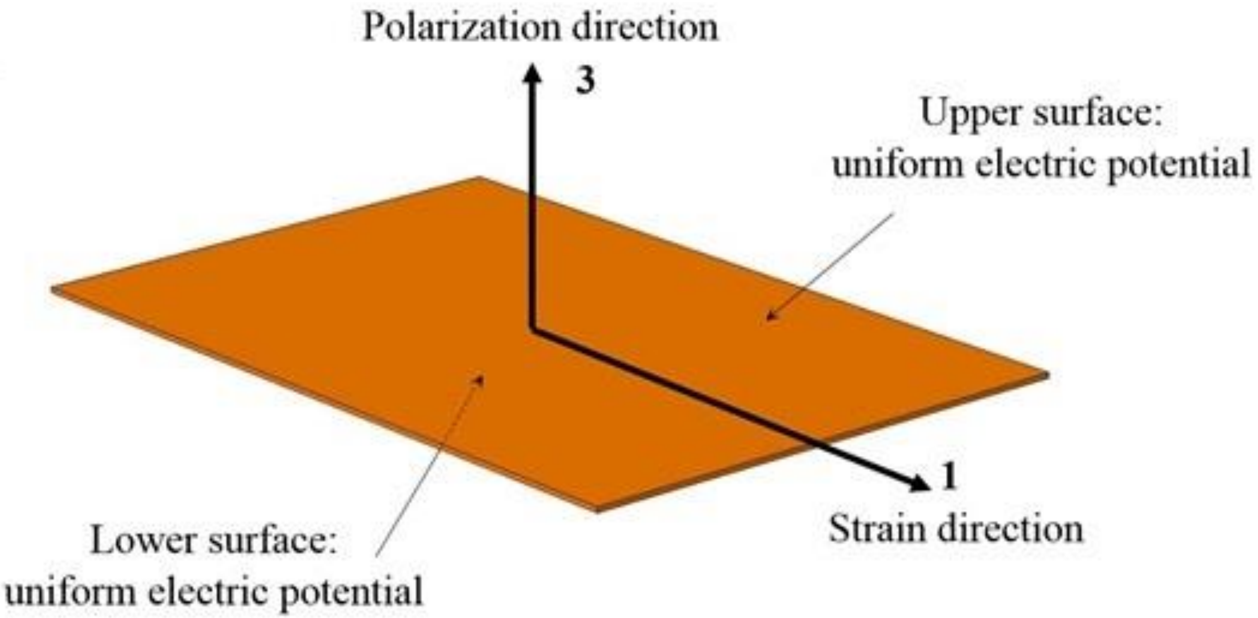
Finite Element Analyses: General Assumptions

General Assumptions

- The FEM model of a hybrid sample does not account for the grips for constraining the specimen to the test equipment.
- A very thin layer of resin has been considered as glue between the substrate and the MFC patches. The layer is 0.075 mm thick.
- A 0.3mm thick layer accounts for the passive area of each MFC patch; an isotropic elastic material has been used to describe the mechanical behavior of the Kapton
- Each ply of the laminated substrate is 0.25 mm thick; thus, the substrate is 1mm thick
- The FE mesh of a sample is made up of 20-node quadratic brick elements with full integration; 20-node quadratic brick elements with the additional electric potential d.o.f have been used for the active area of the MFC

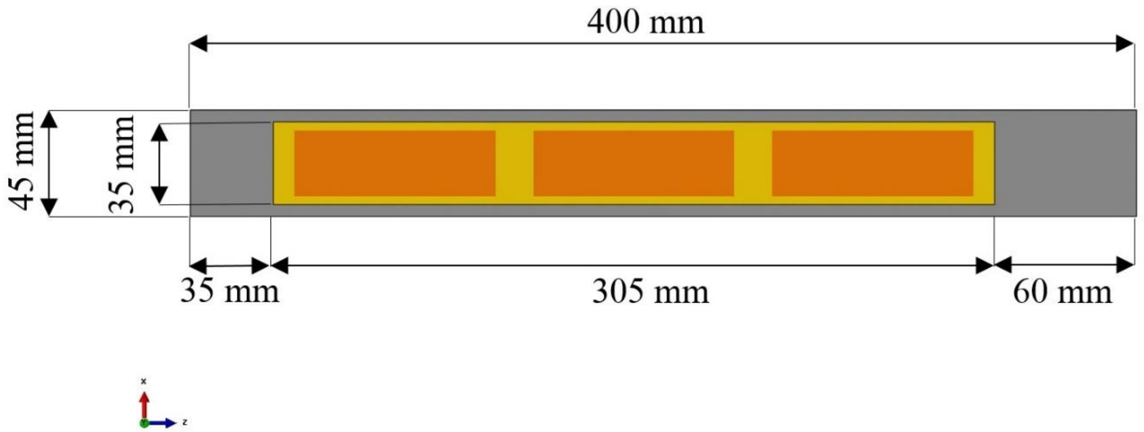
Finite Element Analyses: General Assumptions

- Large displacement formulation has been considered for all analyses.
- The d_{33} operational mode of the MFC P1/F1 types has been modeled as the d_{31} mode; in so doing, an electric potential gradient through the thickness (direction 3) produces strain in the fiber direction (direction 1). This allows us to apply a uniform electric potential on the upper and lower surface of a MFC.
- A clamped boundary condition has been used to constrain the nodal displacements of the root section of the specimen.

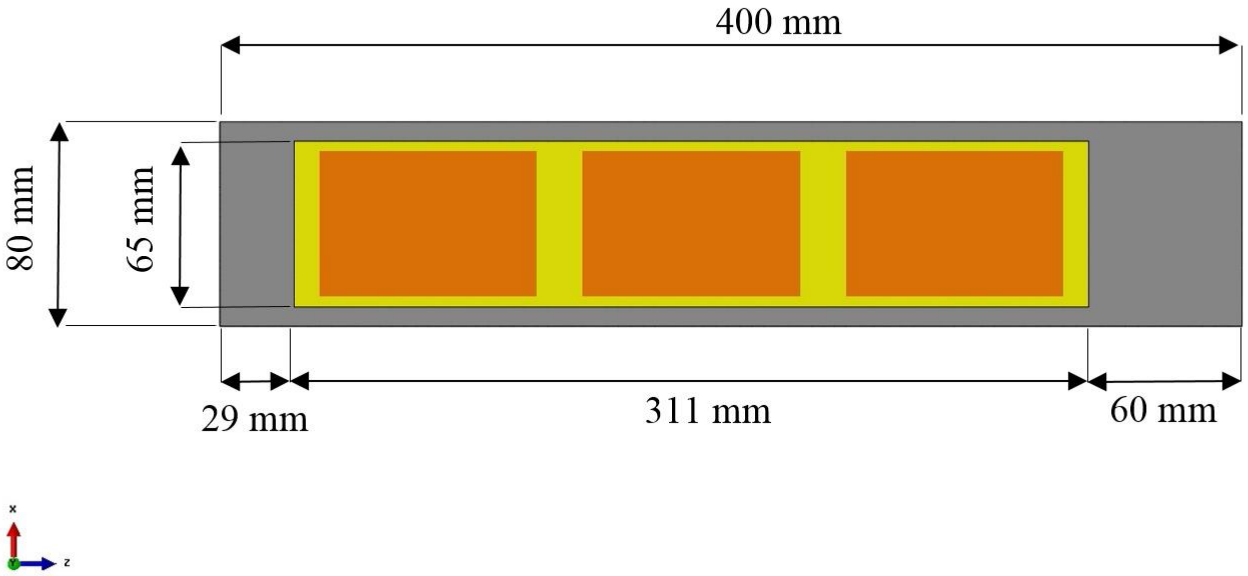


Finite Element Models

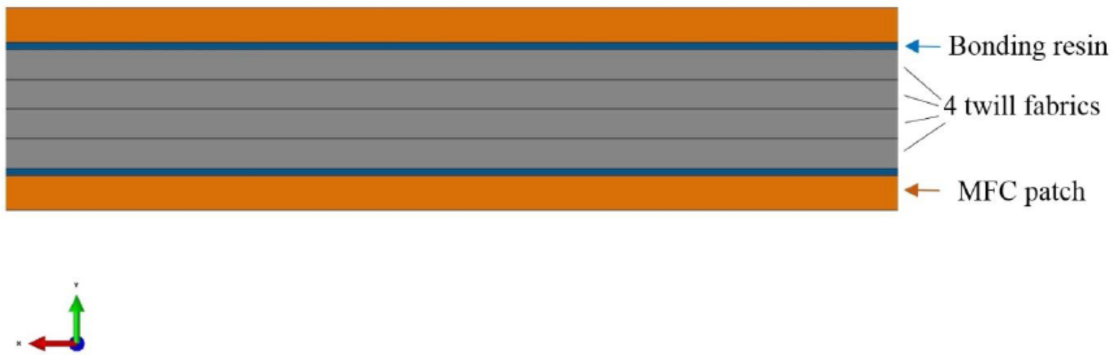
bending specimen



torsion specimen



cross-section of a specimen

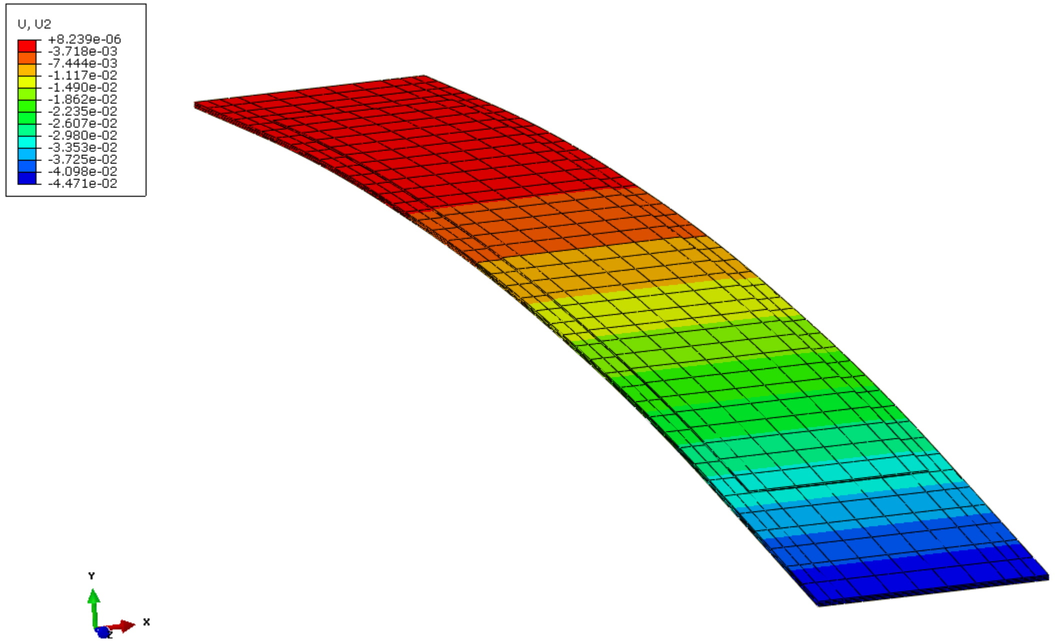


Finite Element Analyses: Bending

Graphite/epoxy laminated substrate

Ply Id	Sequence 1	Sequence 2	Sequence 3	Sequence 4
1	+45/-45	0/90	+45/-45	+45/-45
2	0/90	+45/-45	0/90	0/90
3	0/90	+45/-45	0/90	0/90
4	+45/-45	0/90	+45/-45	+45/-45

	Vertical displacement at the free end of the sample [mm]	
Stack. Seq. Id	Voltage +500V/-500V	Voltage +1500V/-500V
1	22.82	44.71
2	17.25	34.36
3	16.76	33.42
4	24.82	48.71



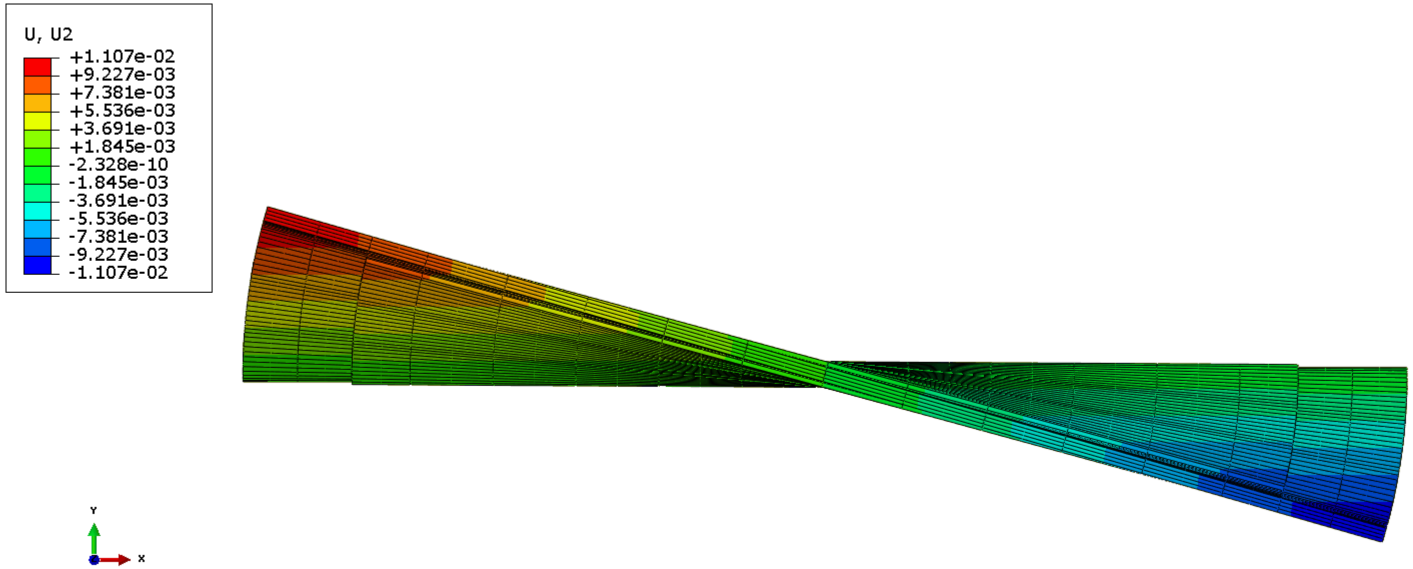
Finite Element Analyses: Bending

Glass/epoxy laminated substrate

	Vertical displacement at the free end of the sample [mm]	
Stack. Seq. Id	Voltage +500V/-500V	Voltage +1500V/-500V
1	25.82	50.90
2	23.78	47.14
3	23.52	46.63
4	26.27	51.81

Finite Element Analyses: Torsion

Graphite/epoxy laminated substrate



Data at the free end of the sample		
Stack. Seq. Id	Vertical displacement [mm]	Torsion angle [deg]
1	8.18	11.56
2	11.07	15.47
3	10.96	15.32
4	8.68	12.24

Results obtained by supplying the maximum operating voltage (equal to +1500V)

Finite Element Analyses: Torsion

Glass/epoxy laminated substrate

	Data at the free end of the sample	
Stack. Seq. Id	Vertical displacement [mm]	Torsion angle [deg]
1	11.28	15.75
2	12.52	17.38
3	12.26	17.04
4	11.67	16.26

Results obtained by supplying the maximum operating voltage (equal to +1500V)

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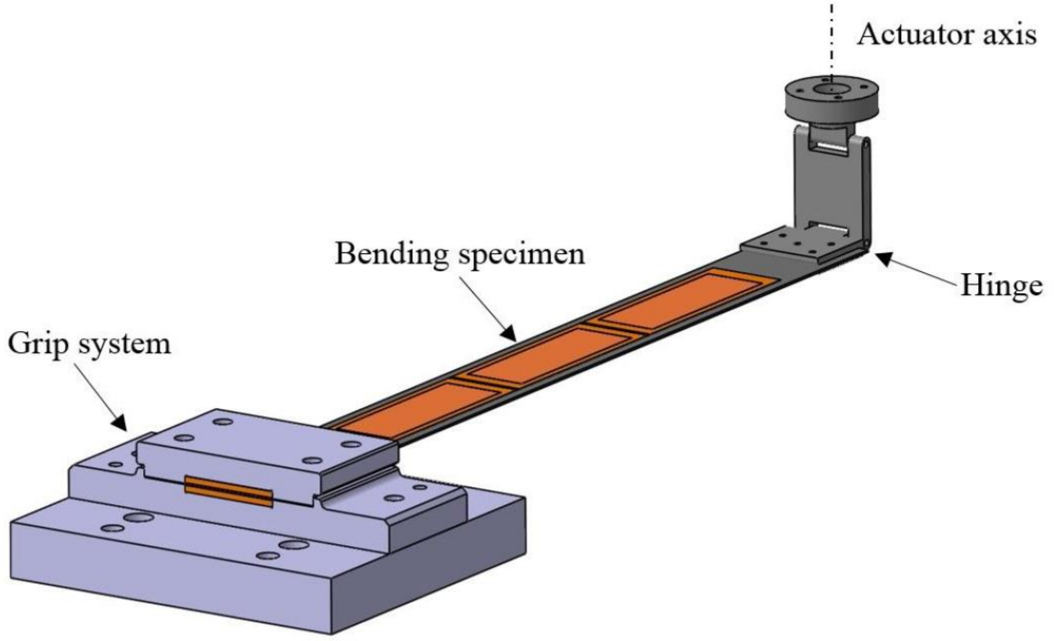
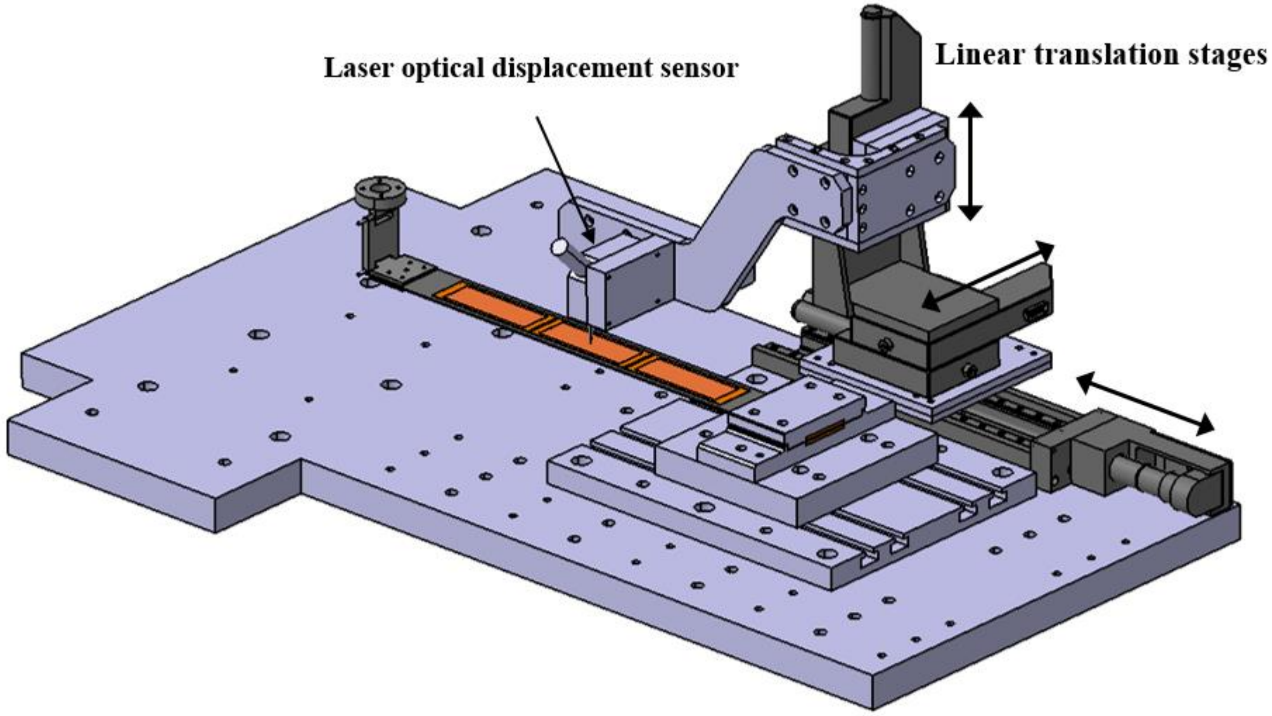
Test Equipment: Bending specimen

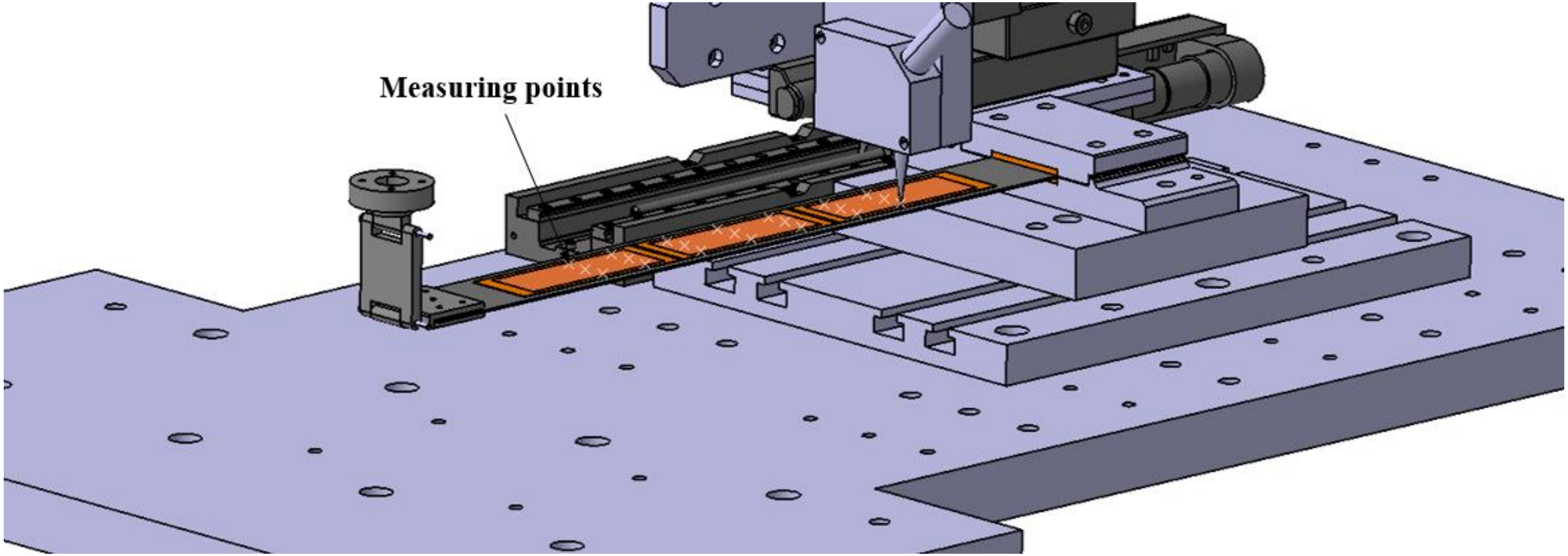
- 3 linear stage allow a laser optical displacemen sensor to measure the deformed shape of a specimen in several points
- The displacement measuring range of the sensor is about 10 mm; measurements range from 20 mm to 30 mm, with respect to the specimen surface





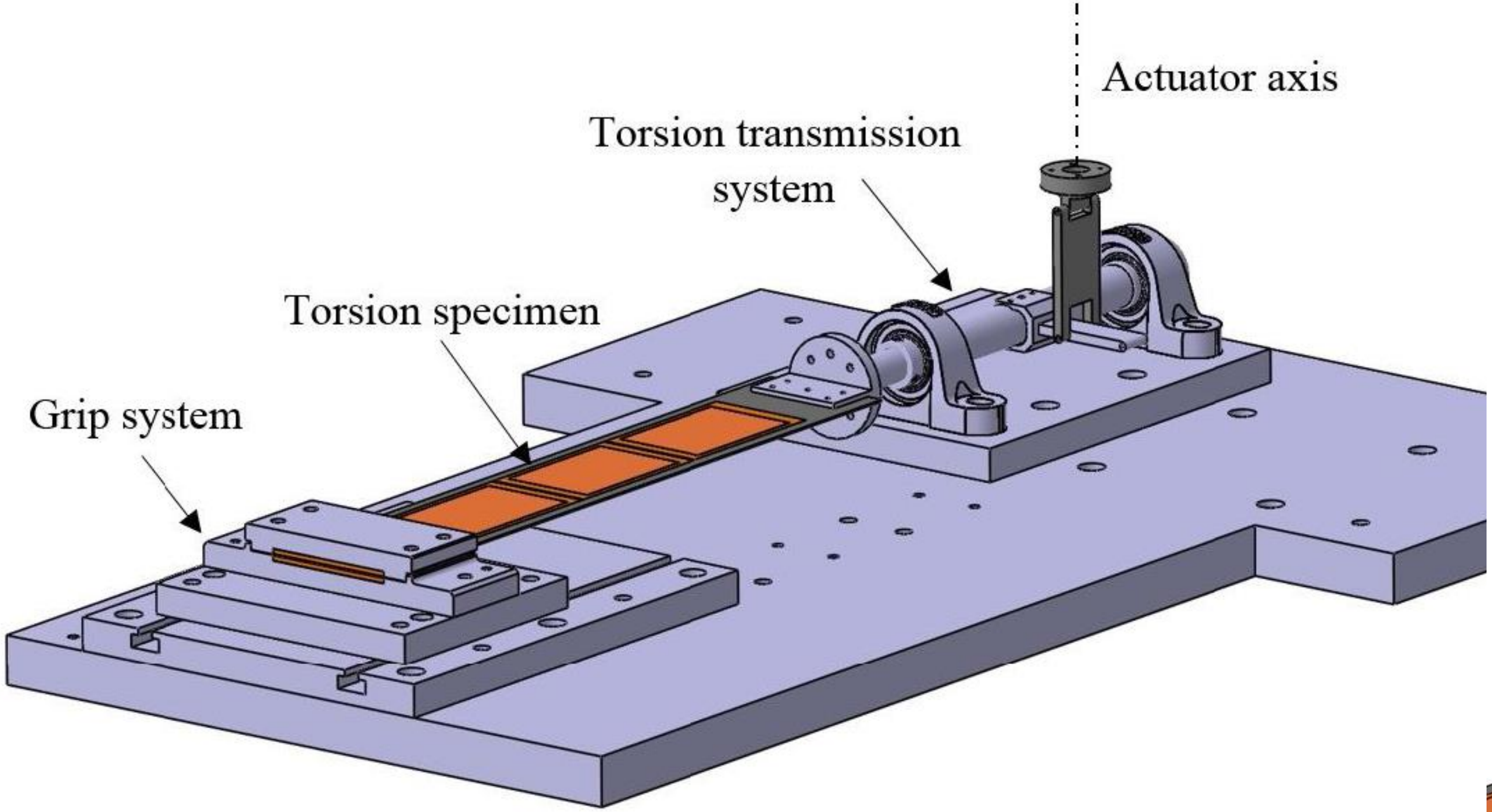
Test Equipment: Bending specimen

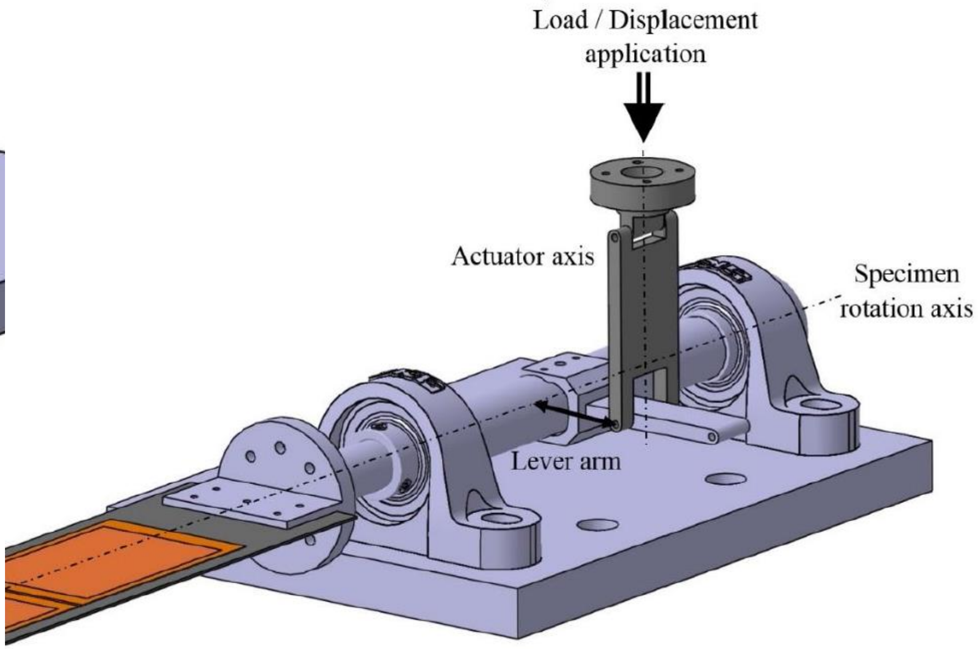
- for bending samples a matrix of 21 measuring points have been used



Test Equipment: Torsion specimen

- Frame for transferring torque moment

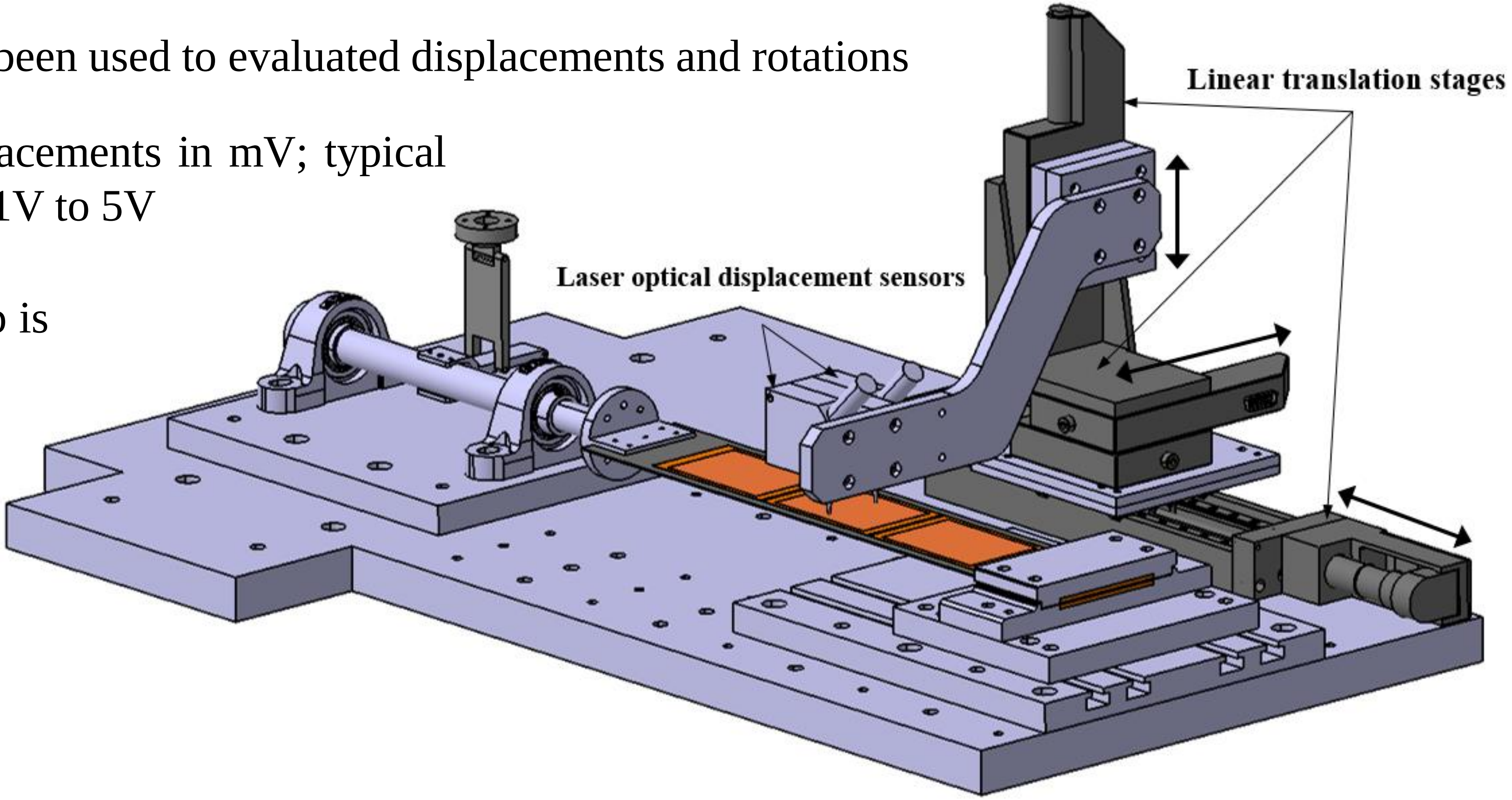




Test Equipment: Torsion specimen

- 2 laser optical displacement sensors have been used for torsion specimens
- 14 measuring points have been used to evaluated displacements and rotations
- the sensors measure displacements in mV; typical measurements range from 1V to 5V
- The following relationship is valid:

$$1\text{mm} \equiv 400\text{mV}$$

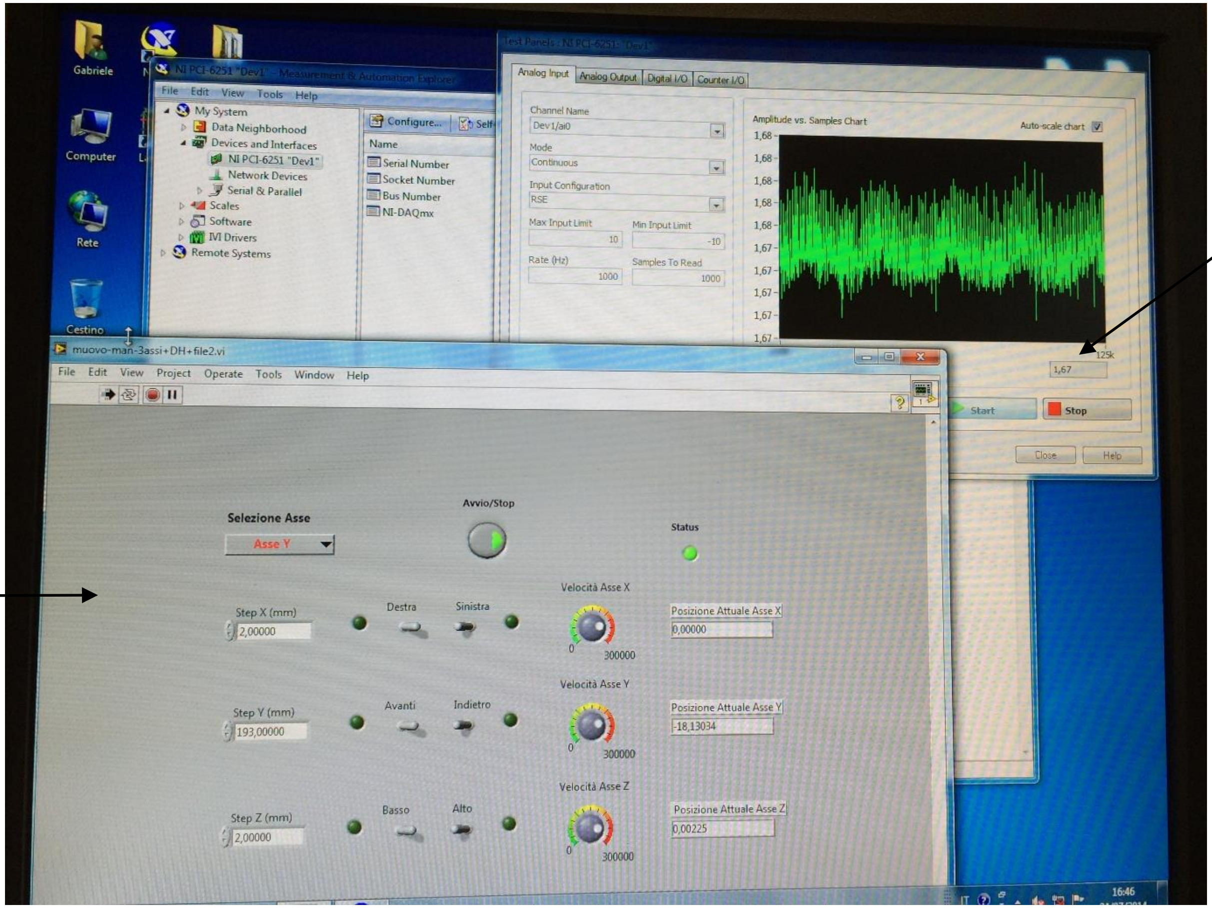


Test Equipment: LabView

- A LabView user program has been developed to move the linear stages along the three directions

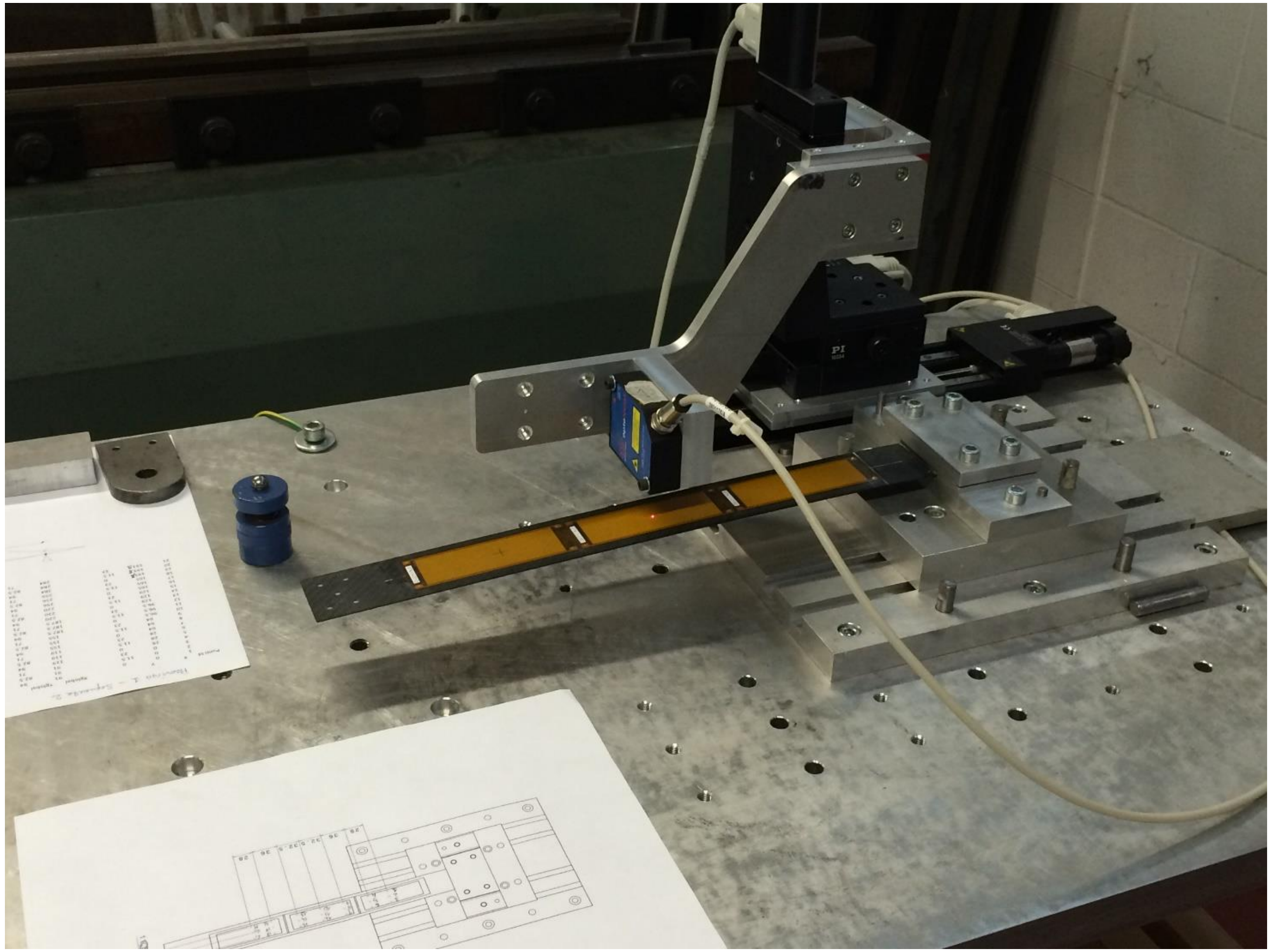
Test panel showing the measurements

Interactive GUI used for moving the linear stages



Test Equipment

High voltage six-channel amplifier; one channel is used to give a positive voltage to the lower MFC patch close to the clamped section of a bending specimen



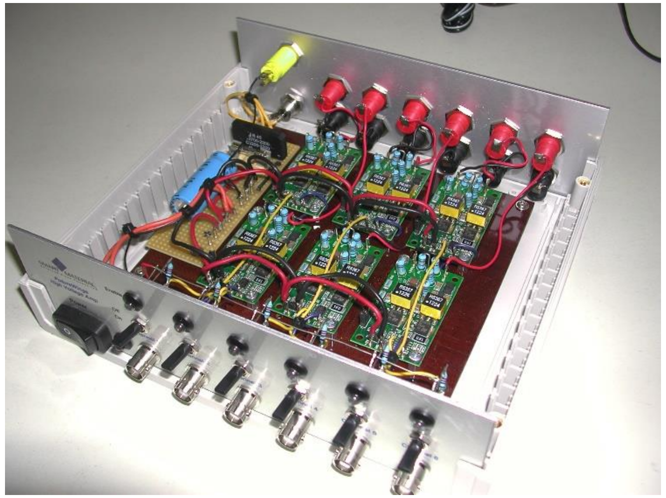
A typical measurement of the deformed shape of a bending specimen due to its weight

Test Equipment: High Voltage six-channel Amplifier

- Electric potential gradients have been applied on MFC piezoelectric patches, by means of a high voltage six-channel amplifier

- The basic idea behind the development of a six-channel amplifier is that to be able to control each MFC patch separately

- Input voltages range from 0V to 5V correspond to output voltages ranging from -500V to 1500V; more precisely, the input voltage range from 0V to 2.5V is equivalent to an output voltage ranging from -500V to 0V, that ranging from 2.5V to 5V corresponds to a voltage ranging from 0V to 1500V.



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Bending tests

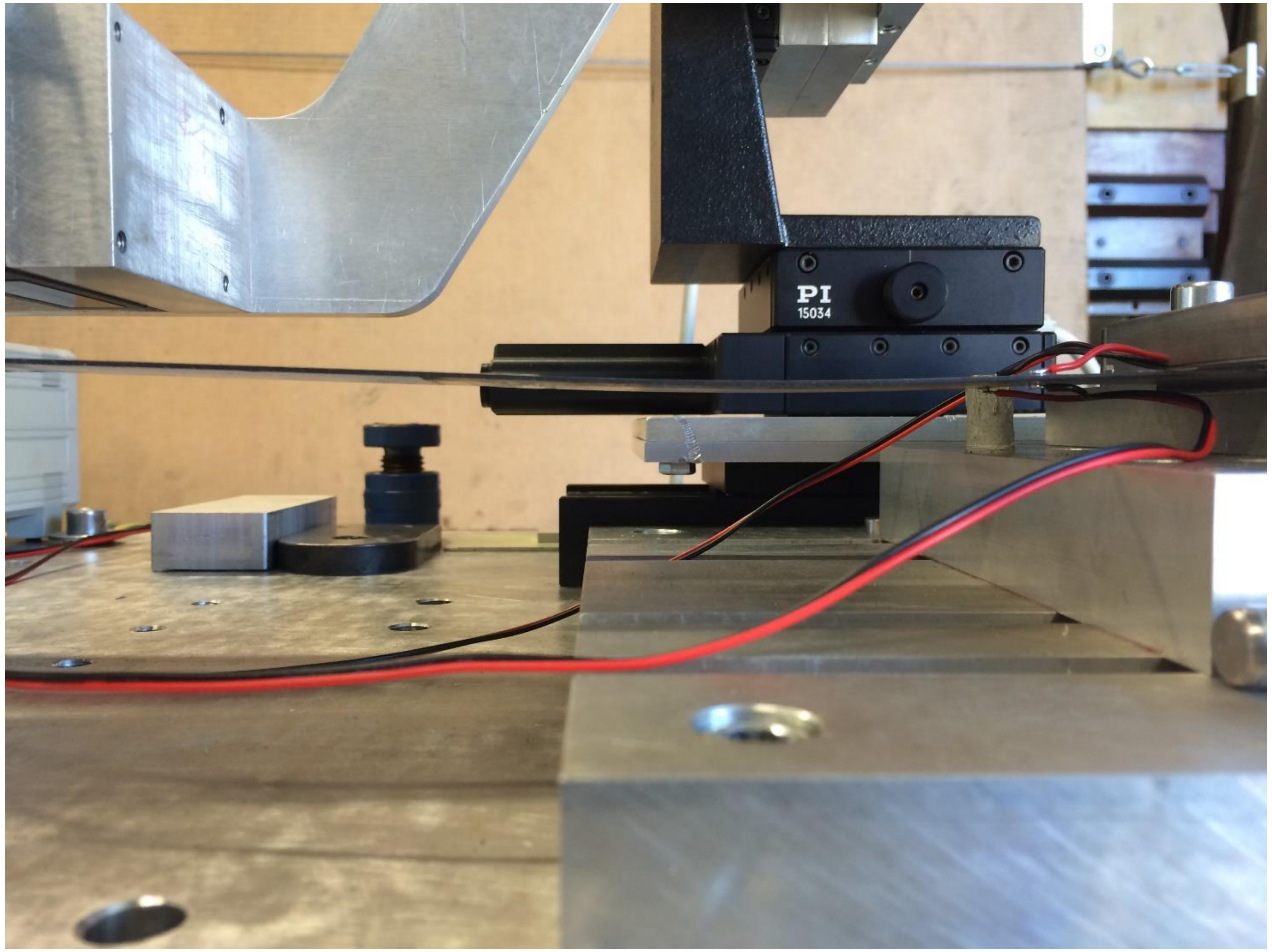
- As a mechanical load, all testing specimens are subjected to their weight; thus, they undergo a bending stress

- In addition, due to manufacturing process, specimens are characterized by an initial undeformed shape, which is different from the ideal one; thus, the resulting deformed shape is assumed as the reference one

- In contrast to the reference deformed shape, MFC patches have been stressed in order to promote an opposite bending stress; this has been done by supplying positive voltages to lower MFC patches and negative ones to the upper MFC patches.

- Thus, an input voltage range from 0V to 2.5V (equivalent to -500V to 0V as output of the HV amplifier) has been applied to the MFC patches which behave as contractors, whereas the voltage range from 2.5V to 5V has been used for MFC elongating actuators.

Bending tests

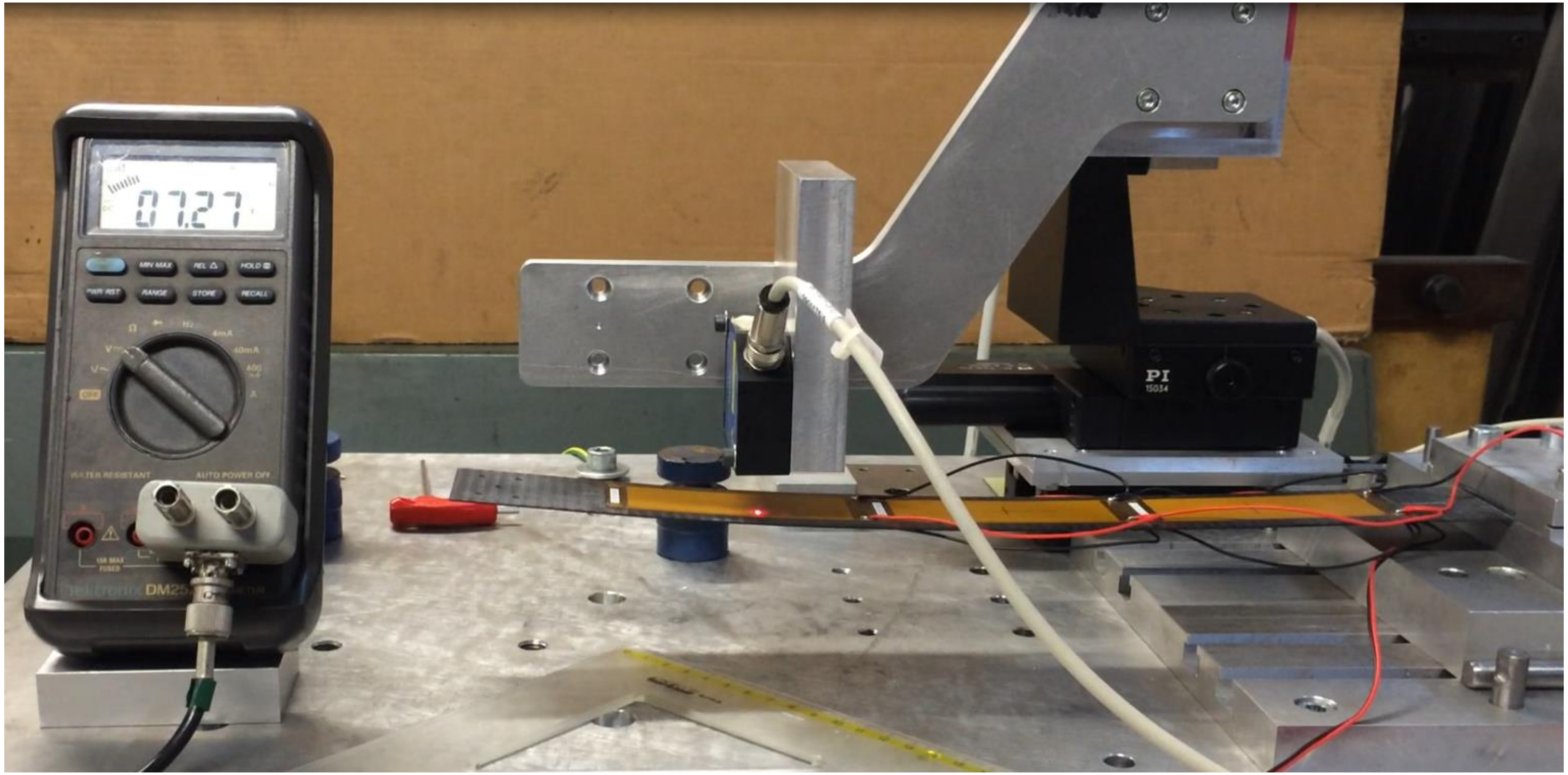


Negative voltage applied to the upper MFC

Positive voltage applied to the lower MFC

A local deformation of a sample due to the behavior of the MFC patches close to the clamped section

Bending tests



Lower MFC connected in parallel at a channel of the HV amplifier

A deformed shape of a sample due to a voltage of +1400V applied to the lower MFC patches

Bending tests: the weight effects