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Linear modeling of elongated bending EAP actuator at large deformations

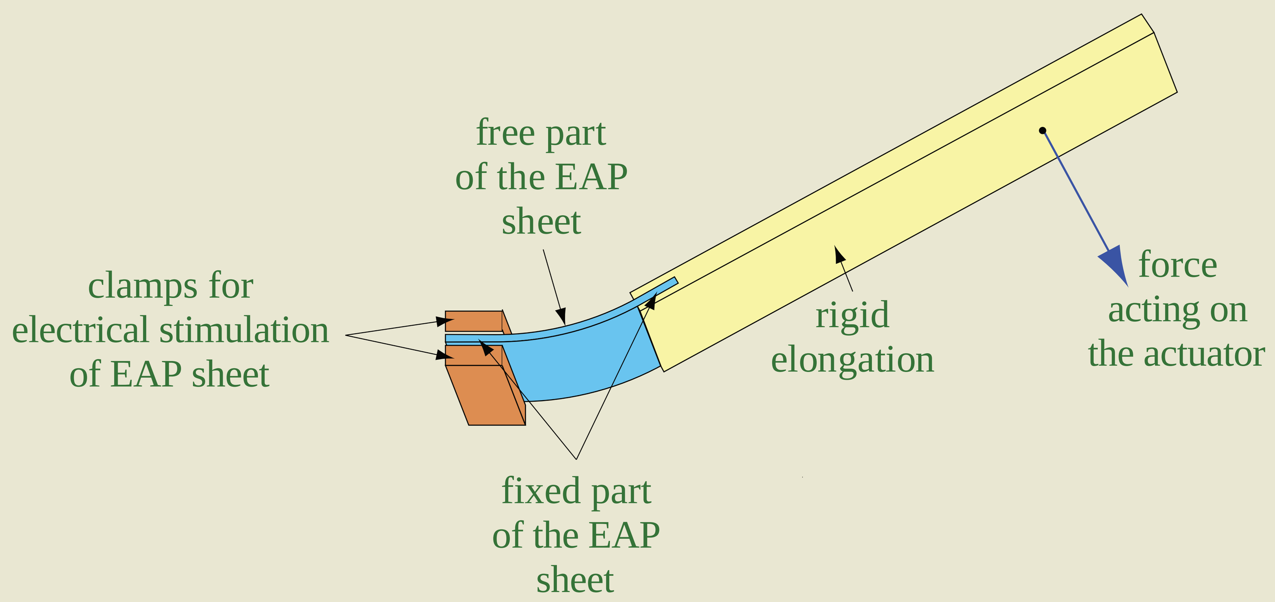
Indrek Must[a], Mart Anton[ab], Maarja Kruusmaa[ac], Alvo Aabloo[a]

Introduction

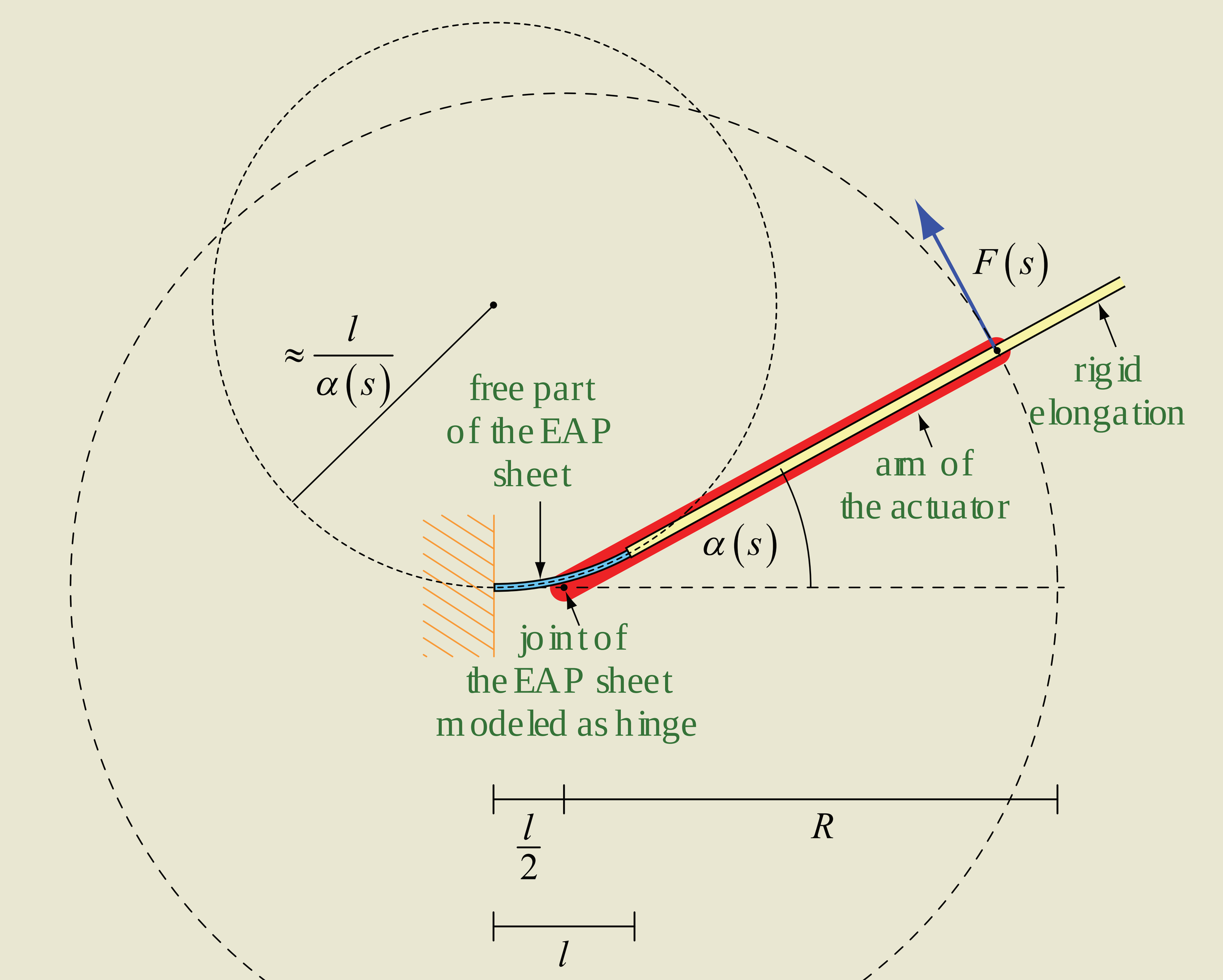
This paper describes a simple linear dynamic model of an elongated bending Electroactive Polymer (EAP) actuator applicable with deformations of any magnitude. Introduced model can be used to characterize the properties of different EAP materials. Model is linear and feasible for real-time control.

The Model

The actuator can be described as a joint with axis situated at the distance of half EAP free length in front of a clamp. No inertial nor friction forces are considered in our model.



Type	Meaning	Notation	Unit
Dimensions of the EAP Actuator	Length of free part of the EAP sheet	l	m
	Total length of the fixed part of the EAP sheet	l_c	m
	Width of the EAP sheet	w	m
	Arm length of the actuator	R	m
The parameters of EAP material	Normalized bending stiffness of EAP	$\bar{B}(s)$	$N\cdot m$
	Normalized electromechanical coupling of EAP	$\bar{K}(s)$	$N\cdot V^{-1}$
	Normalized electrical impedance of EAP	$\bar{Z}(s)$	$\Omega\cdot m^2$
	Initial curvature of EAP	k_0	m^{-1}
Signals in frequency Domain	Angular deflection of the arm	$\alpha(s)$	rad
	Voltage applied to the EAP sheet	$U(s)$	V
	Force output of the actuator	$F(s)$	N
	Electric current passing through the EAP sheet	$I(s)$	A

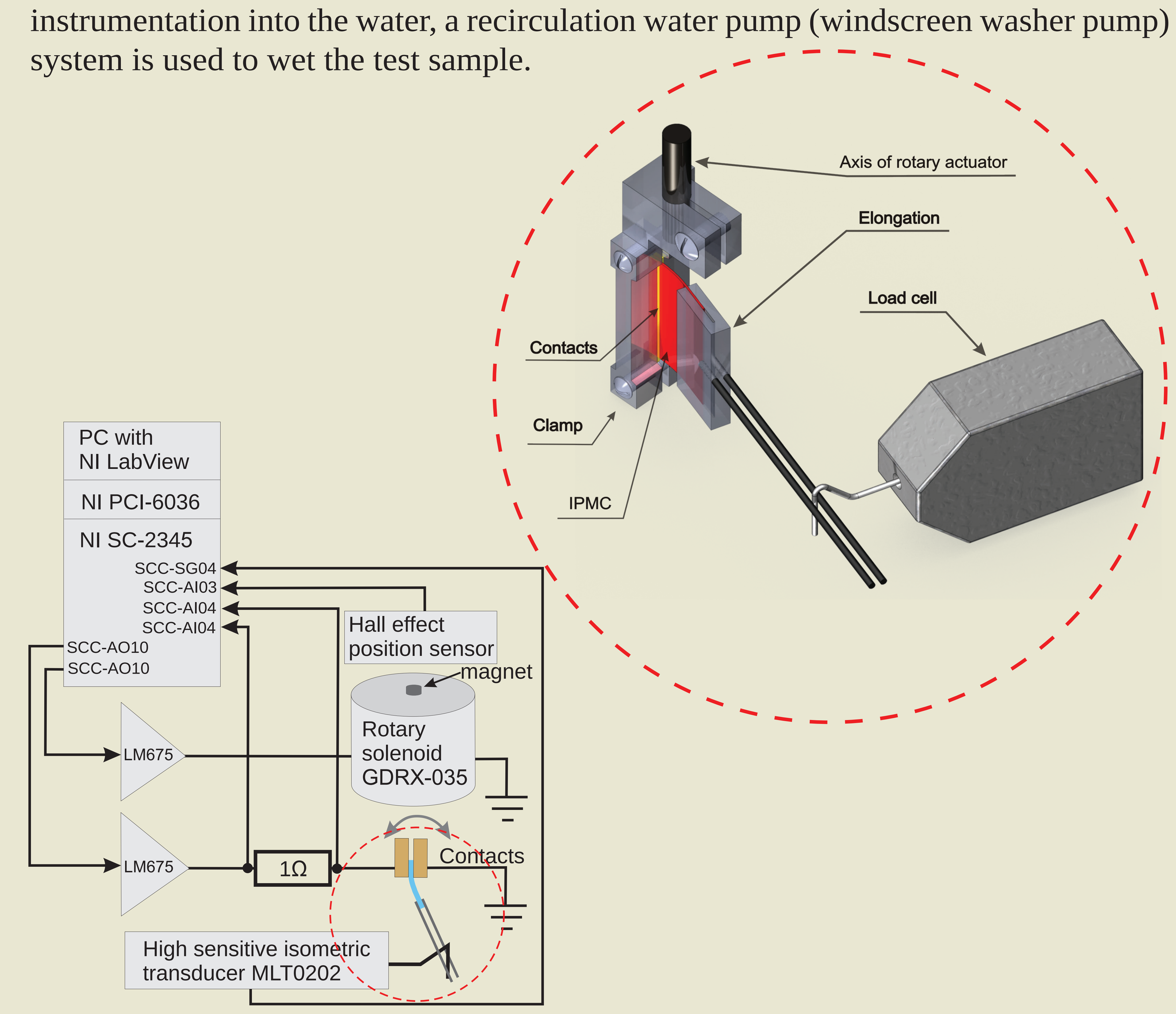


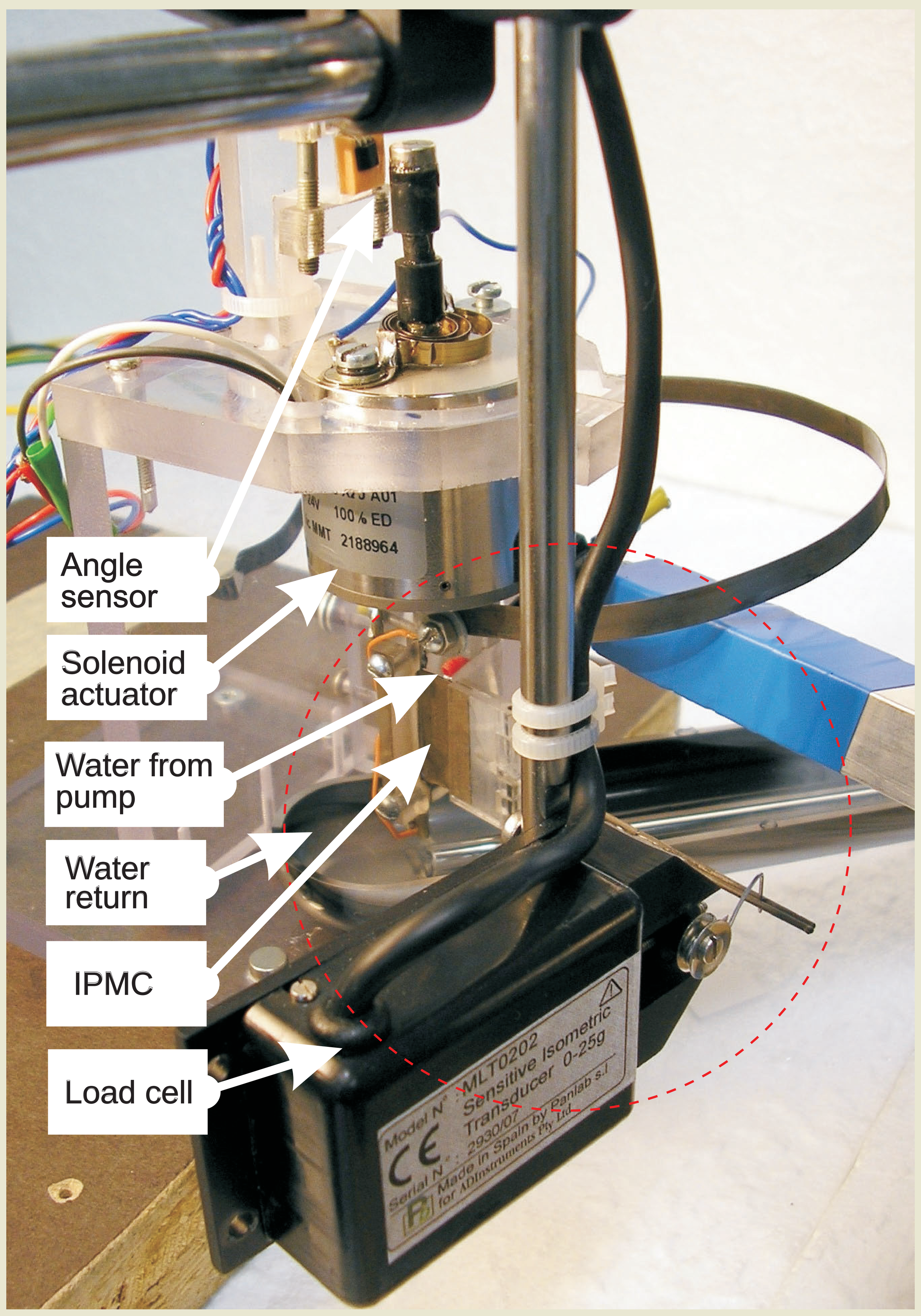
$$F(s)=\frac{w}{R}\left(U(s)\cdot \bar{K}(s)-\left(\frac{\alpha(s)}{l}-\frac{k_0}{s}\right)\bar{B}(s)\right)\qquad I(s)=\frac{U(s)\cdot w\cdot(l+l_c)}{\bar{Z}(s)}$$

Experimental device

The actuator is oriented so that it bends at the horizontal plane, therefore gravity does not affect the measurements. In our system setup not the elongation but the clamp can be moved on a circular trajectory to achieve a desirable curvature of the test sample, therefore inertial forces can be considered negligible.

In order to keep the hydration level constant, while avoid immersing the test instrumentation into the water, a recirculation water pump (windscreen washer pump) system is used to wet the test sample.





EAP material used in the experiments

Ionometric Polymer-Metal Composite (IPMC) from Environmental Robotic inc. was used. Initial ionic fluid based solvent has been replaced by water.

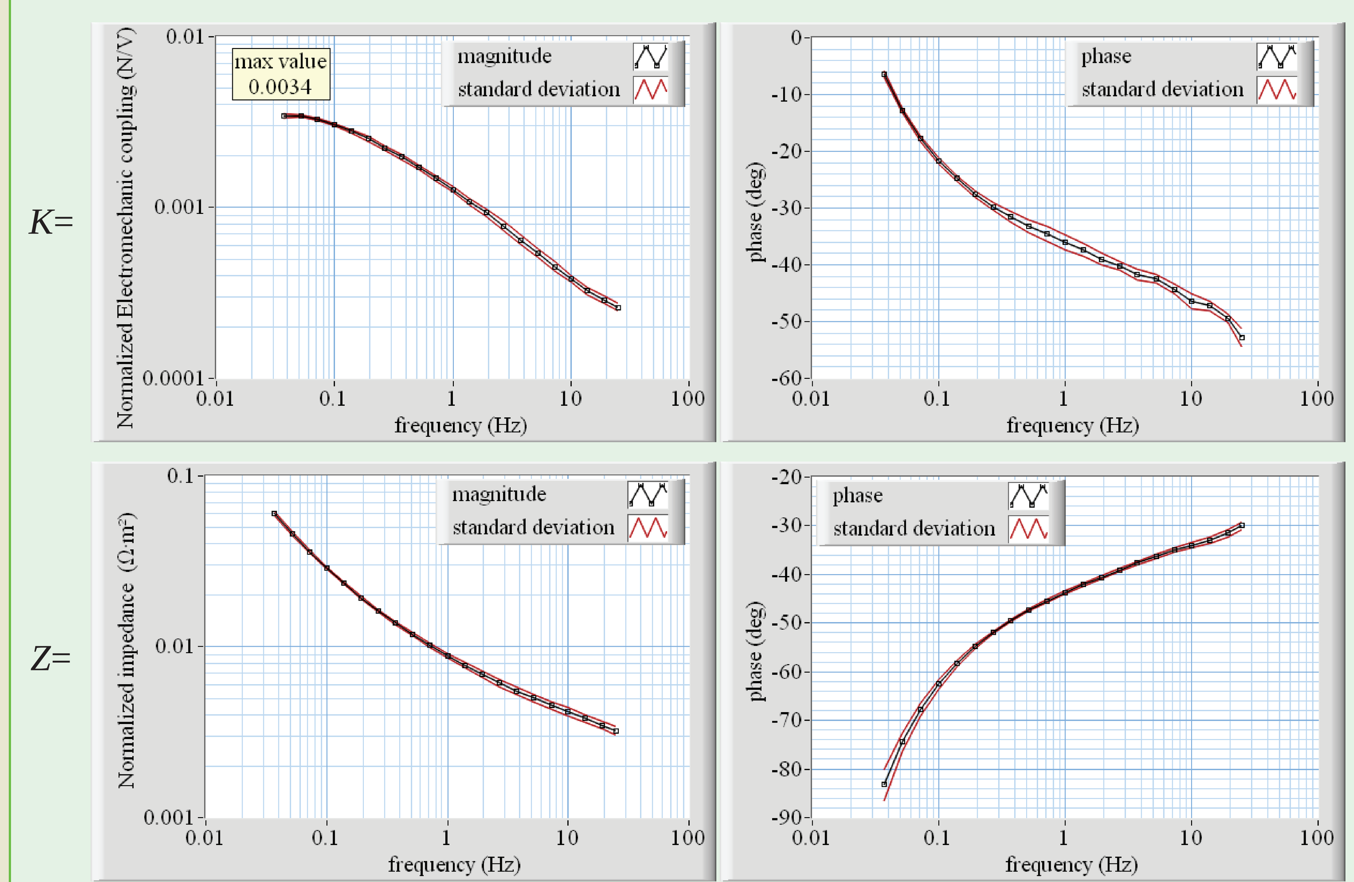
Dimensions of IPMC actuator used in experiments

Four actuators with different geometry were constructed using the same EAP sheet.

Series	l	l_c	w	R
1.	6mm	6.2mm	19mm	35mm
2.	6mm	6.2mm	19mm	60mm
3.	8mm	4.2mm	19mm	35mm
4.	8mm	4.2mm	19mm	60mm
5.	6mm	6.2mm	19mm	35mm

The parameters of IPMC material

K and Z where measured at the beginning of each test series.



B and k_0 was measured before every experiment.
The mean value of bending stiffnes B = 0,71 mN·m.
Corresponds equivalent Young modulus E = 388 MPa.
The thickness of the sheet was d = 0.28 mm.

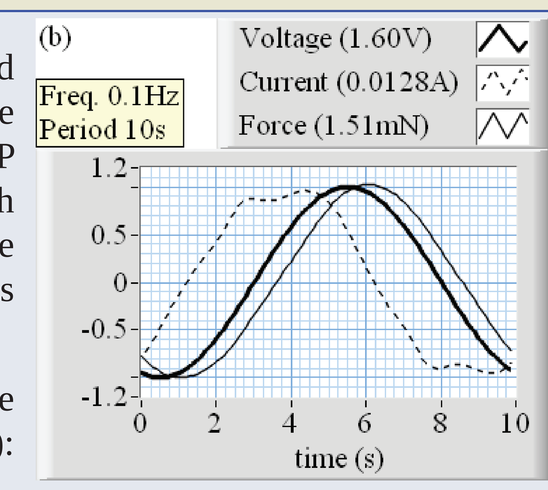
$$\bar{B}=\frac{E\cdot d^3}{12}$$

B can be taken as constant at low frequencies. B varied notably beacuse changes in the hydration level.
Zero curvature k_0 varied from 15 to -24 m^{-1}, Large variation is caused by hysteresis.

The I/O signals of the actuator

The system is excited with sinusoidal voltages and angles with added direct components. Output force of the actuators and current passing through the EAP are measured. In each series experiments with random parameters were performed. Relative force deviation was 14%, relative current deviation was 21%.

Right: a sample of an average cycle (measured at zero angle):



Down: limits of the parameters in random experiments

Parameter	Min	Max
Voltage – direct component	-0.01V	0.2V
Voltage – alternating amplitude	0V	1.57V
Deflection angle – direct component	-15.1deg	24.4deg
Deflection angle – alternating amplitude	0	20.9deg
Frequency	0.0607Hz	27.8Hz

Conclusion

In this paper a large deformation model suitable for all bending EAP actuators is presented. The model considers dynamic behavior, initial curvature of EAP and enables concurrently varying load and position.

The model only holds when all the parameters are uniform along the sheet. This can be achieved when IPMC sheet is sufficently short, has high surface conductivity and current is low enough.

Acknowledgements

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[a] IMS Lab, Institute of Technology, Tartu University, Nooruse 1, 50411 Tartu, Estonia
[b]Department of Electrical & Computer Engineering, Michigan State University, East Lansing, MI 48824, USA
[c]Center for Biorobotics, Tallinn University of Technology, Akadeemia tee 15A, 12618 Tallinn, Estonia

Contacts:
Indrek Must: indrekm@ut.ee; Mart Anton: antonm@msu.edu;
Alvo Aabloo: alvo@ut.ee; Maarja Kruusmaa: maarja.kruusmaa@biorobotics.ttu.ee