Identifying material properties of a dielectric motor

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INTRODUCTION

Rotating motor:

Torque → electrical conductivity / electrical permittivity — of the lossy dielectric material

Conductivity of the lossy dielectric:

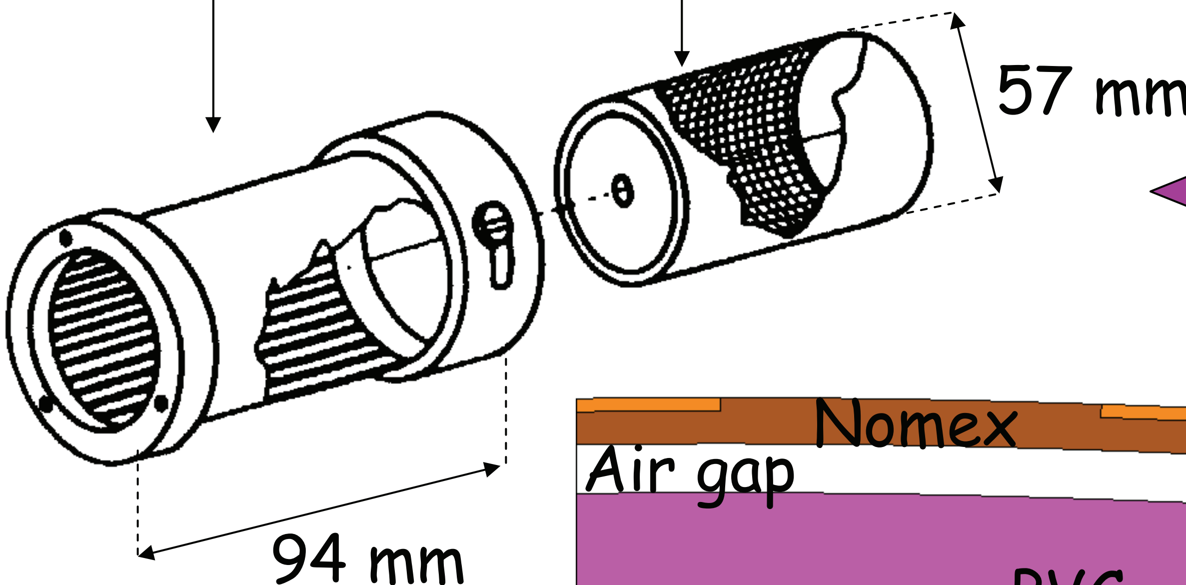
- direct measurement: difficult task
- literature: affected by uncertainties

<u>Aim</u>: to identify the order of magnitude of the material properties, starting from a value of torque.

THE DEVICE (1/3)

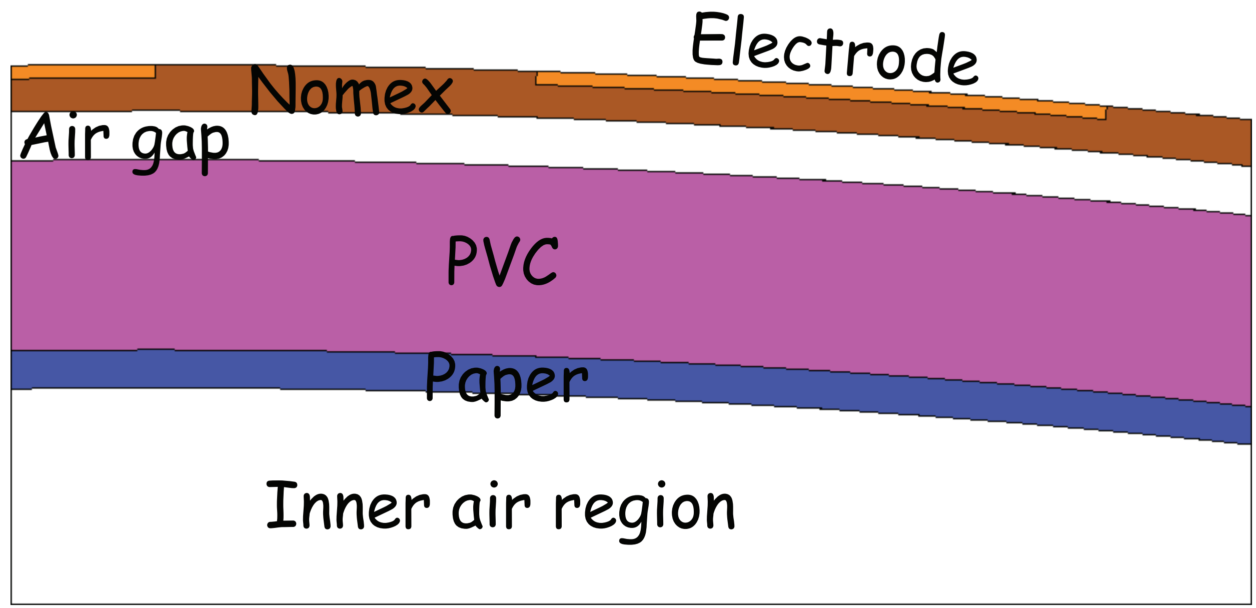
Stator: Nomex + electrodes

Rotor: PVC (ext) + paper (int)



Exploded view

Cross section

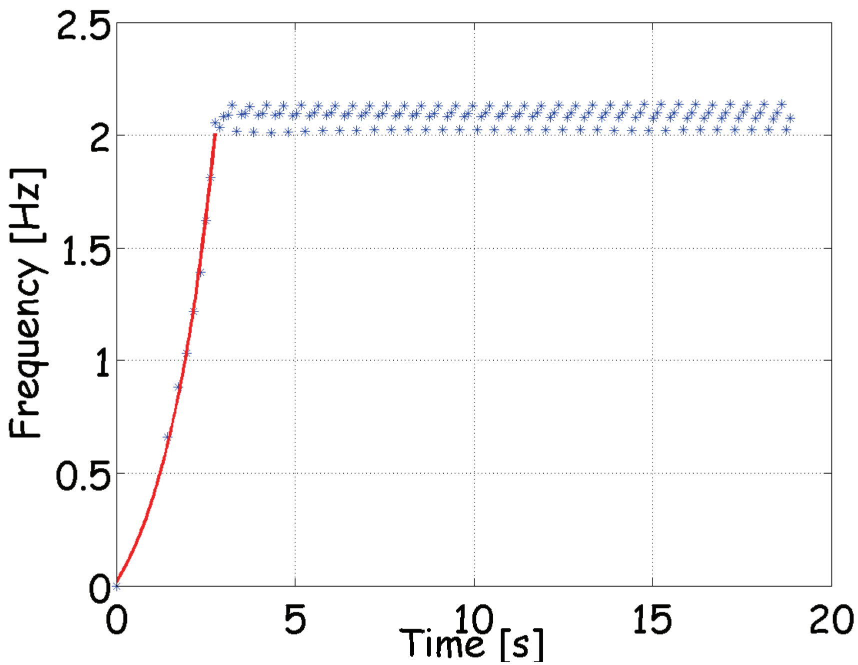


THE DEVICE (2/3)

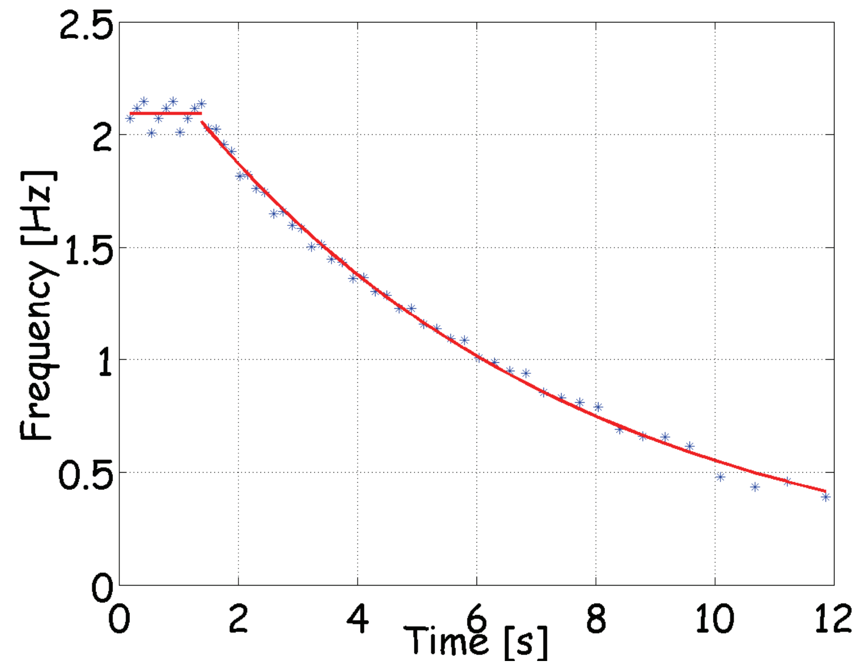
- 72 copper electrodes.
- Three-phase power supply (f=50 Hz, rms-value = 950 V).
- Asynchronous motor.
- Maximum torque: 789 μNm at the nominal speed of 13.1 rad/s.
- Lossy dielectric: paper.

Varying the humidity of the paper (i.e. varying its physical properties), the developed torque changes.

THE DEVICE (3/3)

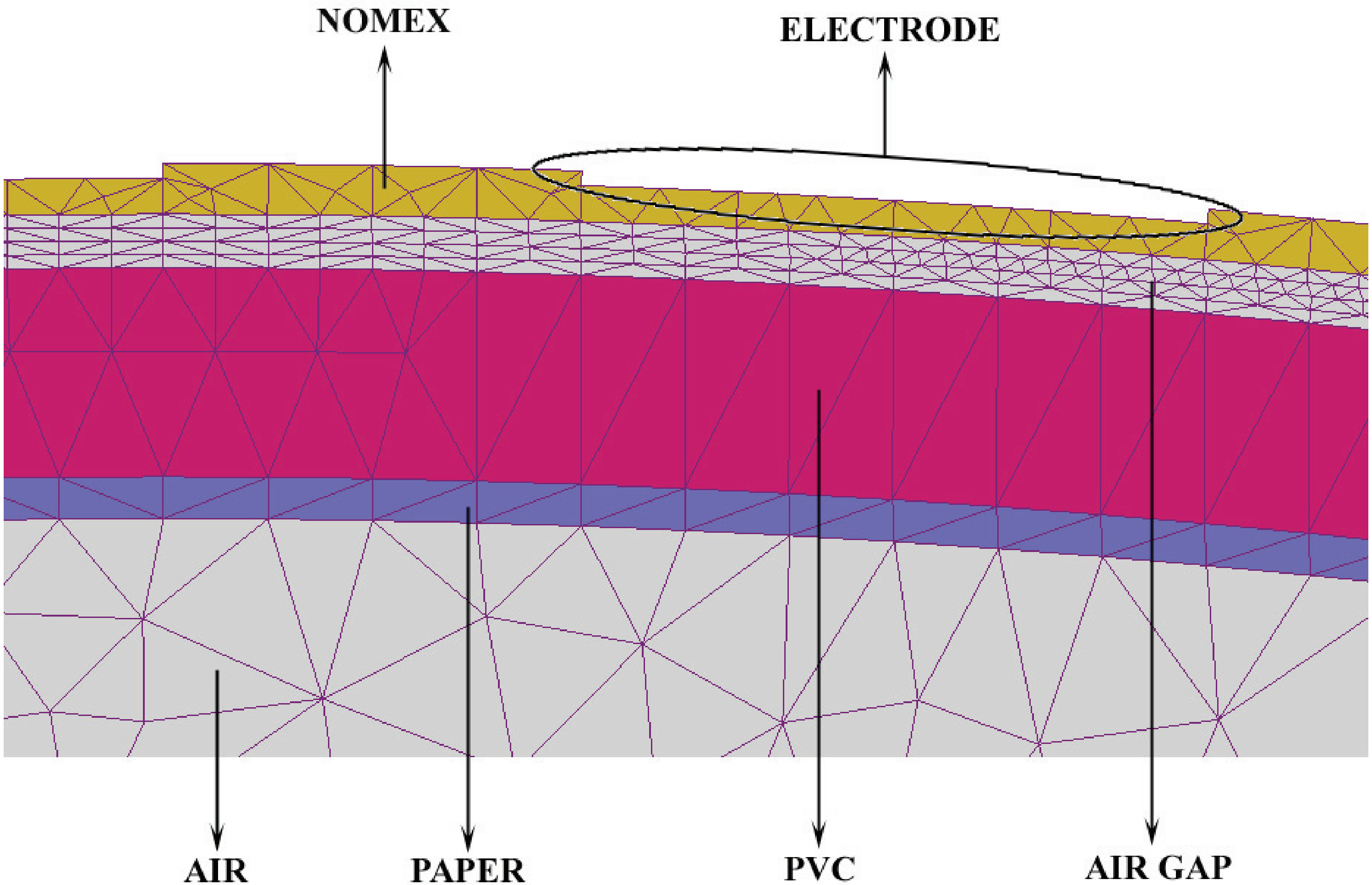


Switch-on response of the motor



Switch-off response of the motor

THE MODEL (1/3)



MESH → Air gap: 4 layers, thickness -> 250 μm each.
Angular resolution: 0.2 deg.
60,774 triangles.

THE MODEL (2/3)

In the frequency domain:

$$\nabla \cdot J = 0$$

$$\nabla \times E = 0$$

$$J = (\sigma + j\omega\varepsilon)E = \sigma E + j\omega D$$

$$\nabla \cdot [(\sigma + j\omega\varepsilon)\nabla U] = 0$$

→ Time-harmonic analysis

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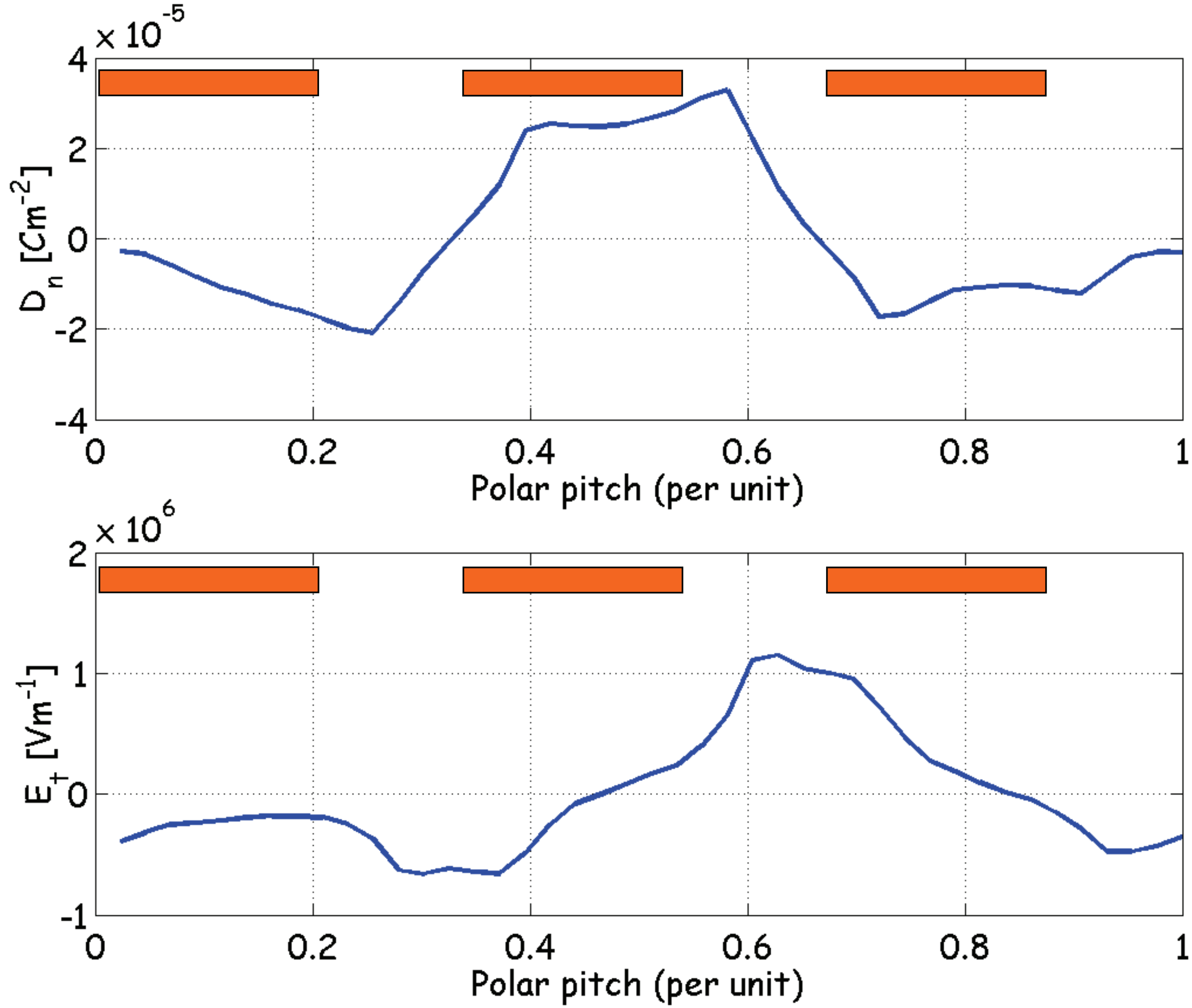
Maxwell stress tensor

Boundary conditions:

$U = U_0$ at the electrodes

$\frac{\partial U}{\partial n} = 0$ elsewhere

THE MODEL (3/3)



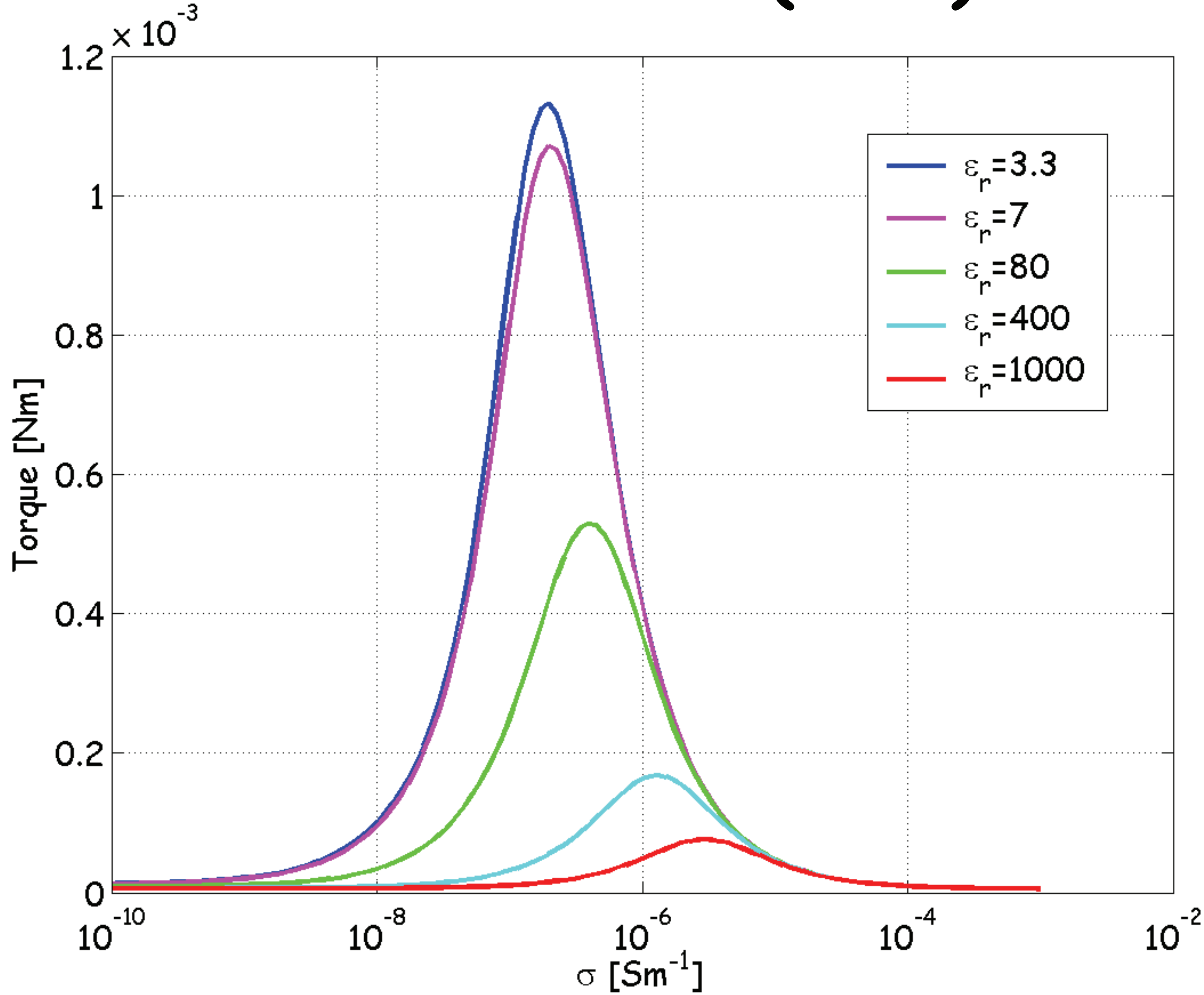
× 10^-5
D_n [Cm^{-2}]
4
2
0
-2
-4
0
0.2
0.4
0.6
0.8
1
Polar pitch (per unit)
× 10^6
E_t [Vm^{-1}]
2
1
0
-1
0
0.2
0.4
0.6
0.8
1
Polar pitch (per unit)

INVERSE PROBLEM

Given a value of torque, e.g. after a measurement on an existing prototype, it is interesting to identify the electrical properties of the lossy dielectric.

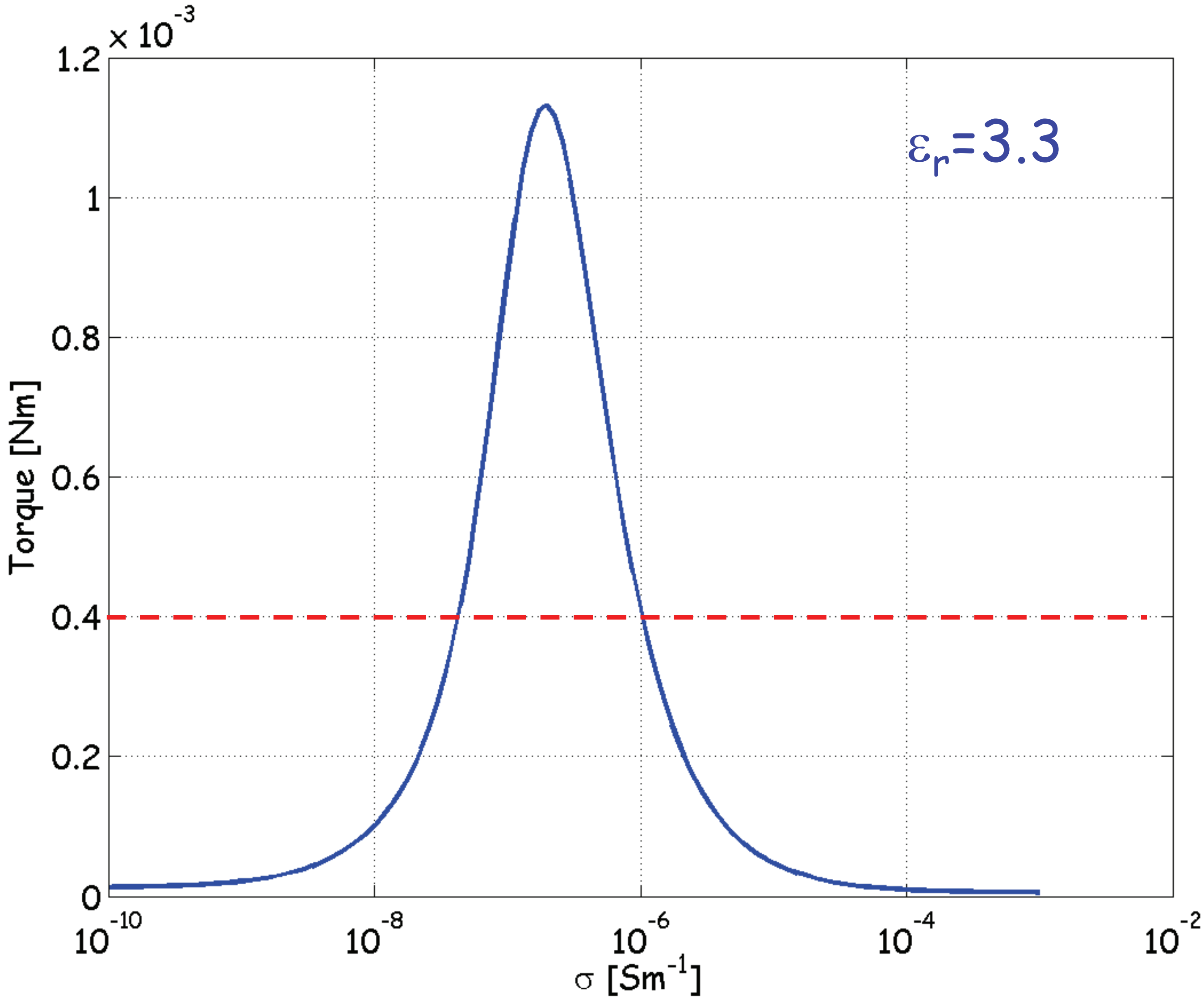
Given the geometry of the motor and its electric supply, find the relationship among starting torque $T(\varepsilon,\sigma)$ *of the motor, permittivity* ε *and conductivity* σ *of the active material.*

RESULTS (1/4)

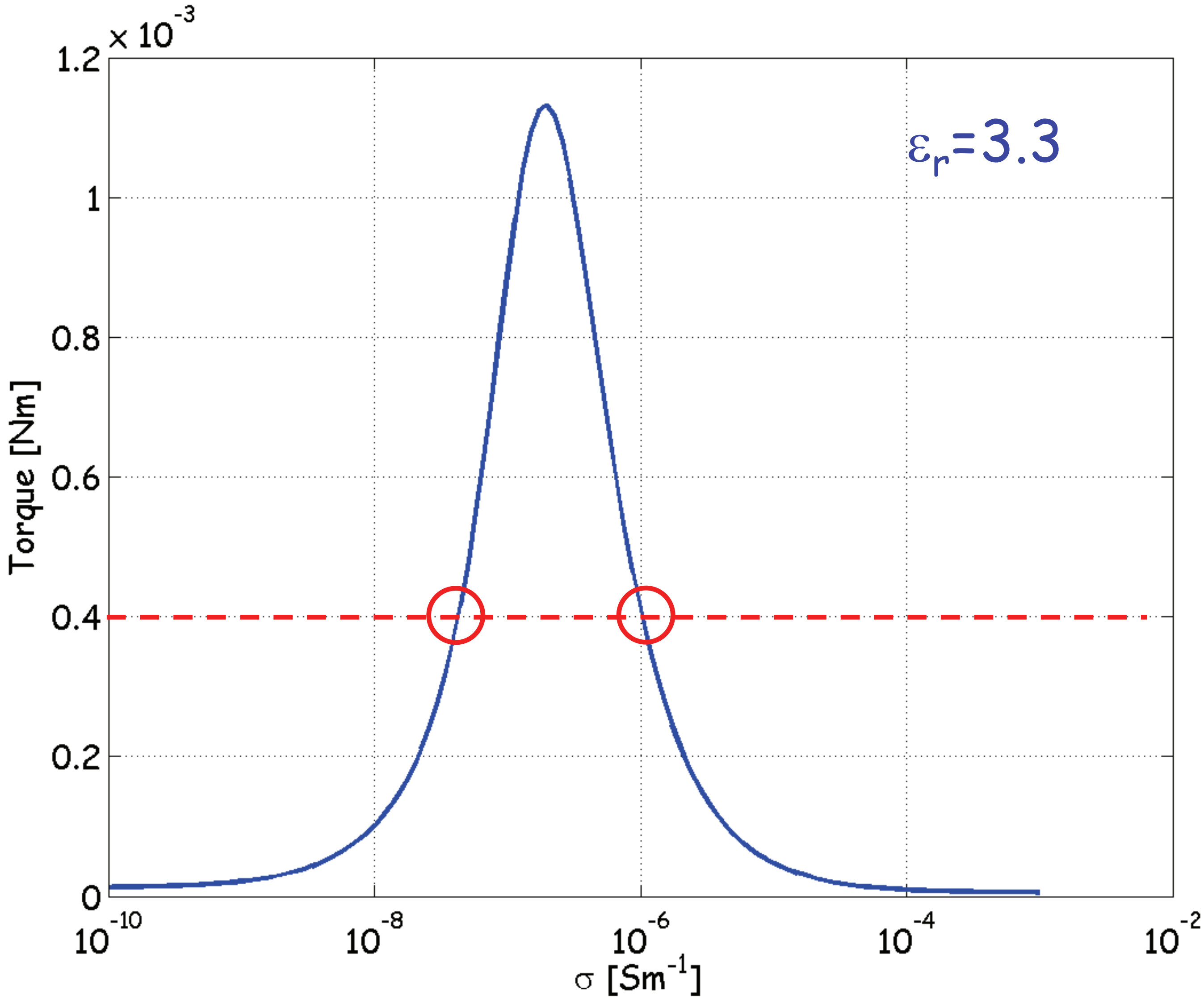


× 10^-3
1.2
1
0.8
0.6
0.4
0.2
0
Torque [Nm]
10^-10
10^-8
10^-6
10^-4
10^-2
σ [Sm^-1]
ε_r=3.3
ε_r=7
ε_r=80
ε_r=400
ε_r=1000

RESULTS (2/4)

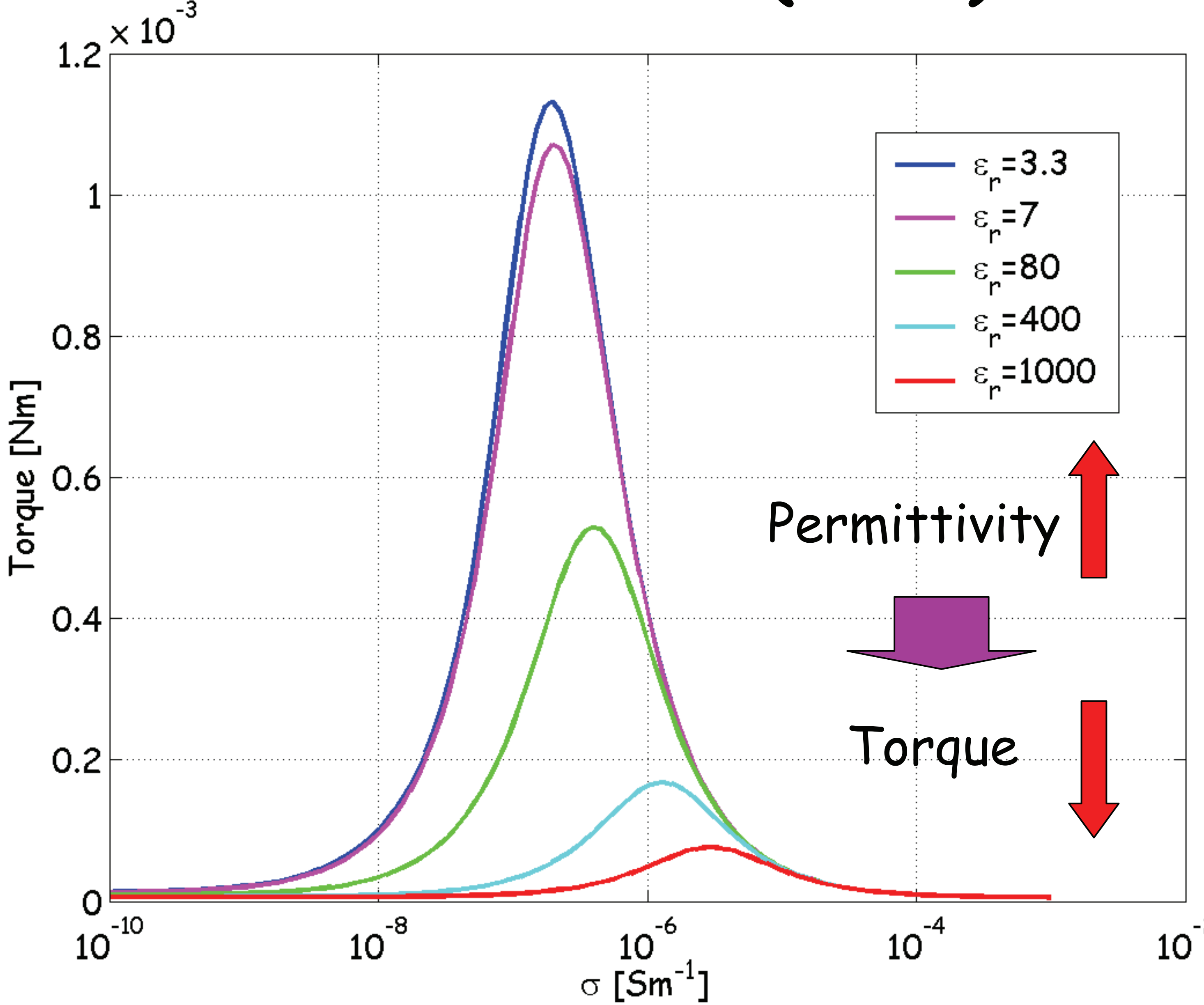


RESULTS (2/4)



ILL-POSEDNESS OF THE INVERSE PROBLEM!!

RESULTS (3/4)


× 10^-3
1.2
1
0.8
0.6
0.4
0.2
0
Torque [Nm]
10^-10
10^-8
10^-6
10^-4
10^-2
σ [Sm^-1]
ε_r=3.3
ε_r=7
ε_r=80
ε_r=400
ε_r=1000
Permittivity
Torque

RESULTS (4/4)

Permittivity ↑ → D radial ↑, E tangential ↓

ε	σ	D_n [Cm^{-2}]	E_t [Vm^{-1}]	T_p [Nm]
3.3	$1.9\ 10^{-7}$	$1.55\ 10^{-5}$	$3.65\ 10^{5}$	$1.12\ 10^{-3}$
7	$2.1\ 10^{-7}$	$1.60\ 10^{-5}$	$3.35\ 10^{5}$	$1.07\ 10^{-3}$
80	$4.0\ 10^{-7}$	$2.20\ 10^{-5}$	$1.80\ 10^{5}$	$0.54\ 10^{-3}$
400	$1.3\ 10^{-6}$	$2.60\ 10^{-5}$	$5.50\ 10^{4}$	$1.70\ 10^{-4}$
1000	$3.0\ 10^{-6}$	$2.70\ 10^{-5}$	$2.4\ 10^{4}$	$0.77\ 10^{-4}$

D radial: calculations at the air gap, under an electrode.

E tangential: calculations in the paper, between two adjacent electrodes

CONCLUSIONS

The performance of a dielectric motor is very critically dependent on the properties of the materials which the motor is made of.

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Numerical model of the motor to *get* information on the values of permittivity and conductivity that *give* rise to *a given* value of starting torque.

The inverse problem is ill-posed → No unique identification of material properties, but…

…help in designing the optimum motor.