Frequency spectrum analysis on the force contribution in a micronewton electromagnetic thruster

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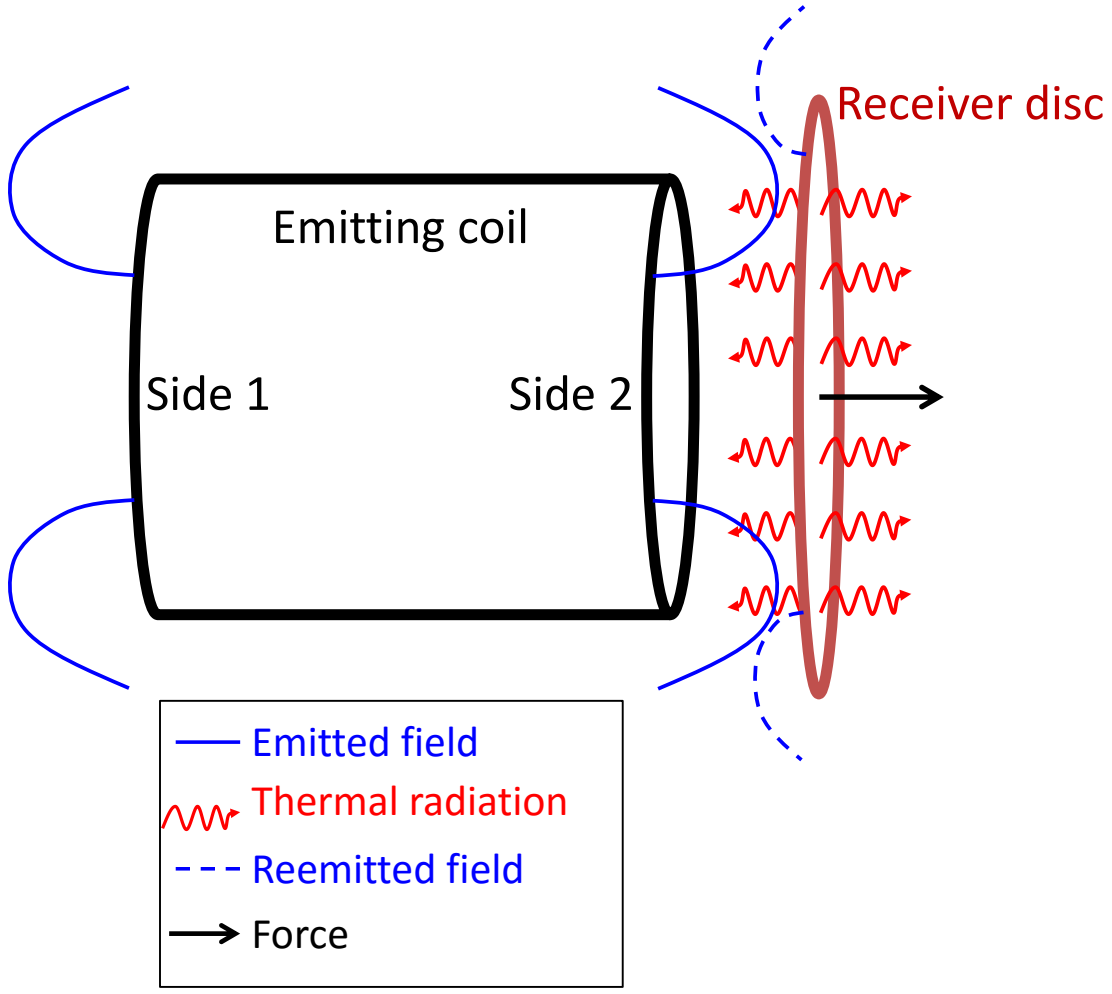
Session B46: Instrumentation I: Detectors, Sensors, Signal Processing & Analysis

11:15 AM–2:03 PM, Monday, March 14, 2016
Room: 311

Sponsoring Unit: GIMS
Chair: James Matey, NIST

Principle

❖Thought experiment initially reported by David P. Goodwin



Electromagnetic energy emitted by an ideal coil:

$$E_{EMCoil} = E_{EMSide\,1} + E_{EMSide\,2}$$

EM waves on Side 1 go to vacuum mainly.
EM waves on Side 2 go to disc and might be lost in vacuum :

$$E_{EMSide\,2} = E_{EMDisc} + E_{EMSide\,2\,lost}$$

Energy balance can be written on disc:

$$E_{EMDisc} = W_{Disc} + E_{Heat} + E_{EMWave}$$

EM waves create Lorentz force on metallic disc
EM waves create eddy currents on metallic disc
Eddy currents create Joule heating (black body radiation)
Eddy currents might reemit EM waves

A RESULTANT FORCE IS EXERTED IN THE COIL-DISC DEVICE

D.P. Goodwin, A possible propellantless propulsion system, AIP Conf. Proc. 552 (2001) 976–978. doi:10.1063/1.1358037.

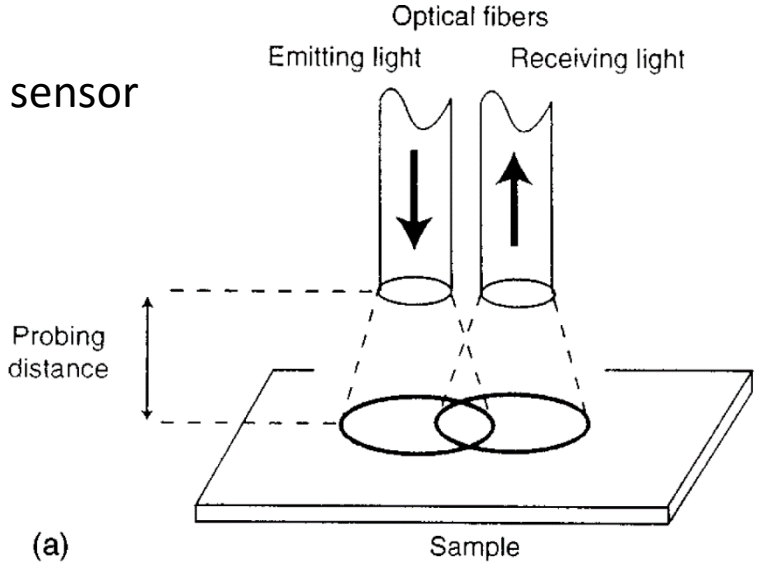
Goals of this work

- Demonstrate experimentally that electromagnetic waves emitted by a coil submitted to a square voltage signal can produce a force on a coaxial metallic disc rigidly attached to the coil. For this observation, a bench for measuring micrometer displacements was used with a coil-disc device hung on a translation pendulum.

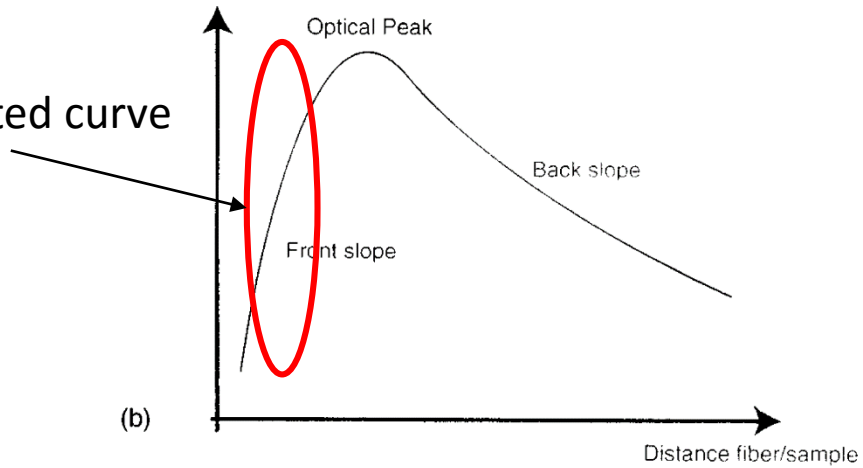
- Develop analytical models predicting the resultant force using different equivalent impedance circuits: R, RL and RLC. For that it is important to consider the so-called square voltage signal in time domain is decomposed in the sum of signal in frequency domain.

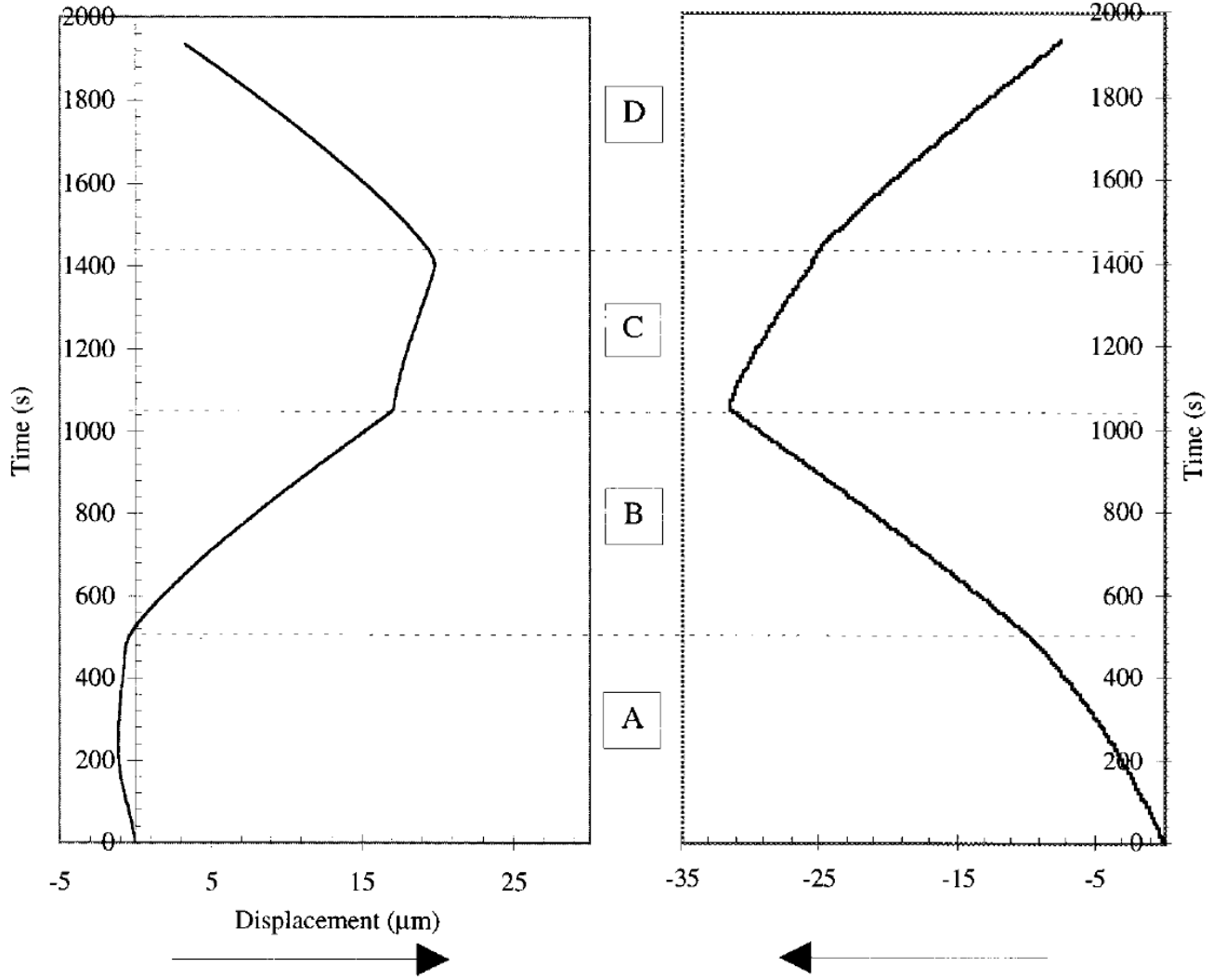
Experimental bench for measuring micrometers

Non-contact sensor



Calibrated curve



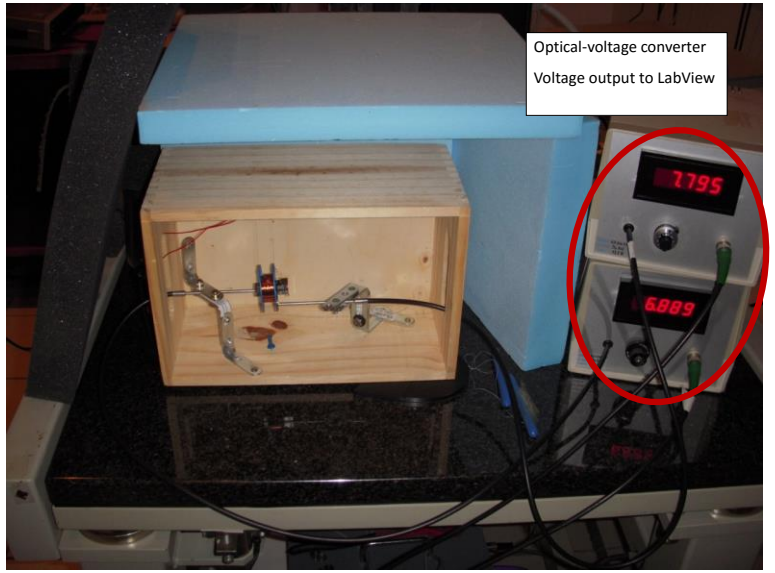


C. Coupeau, J.C. Girard, J. Grilhé, Plasticity study of deformed materials by in situ atomic force microscopy, J. Vac. Sci. Technol. B Microelectron. Nanom. Struct. 16 (1998) 1964. doi:10.1116/1.590234.

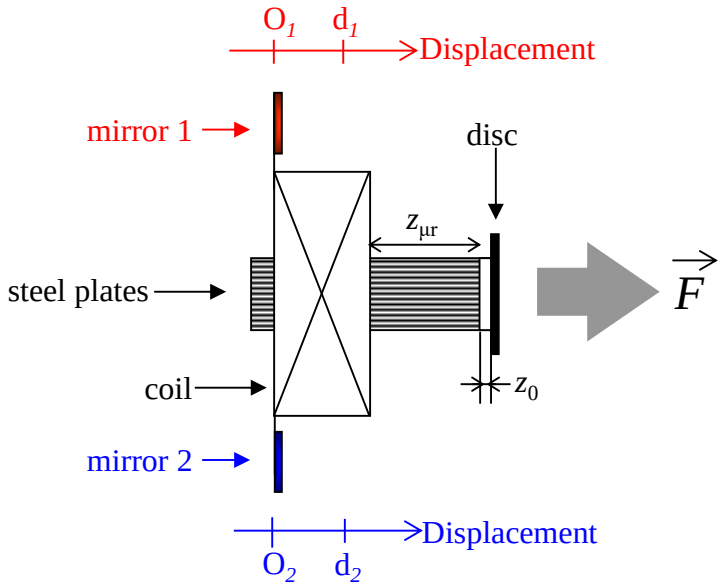
Experimental bench for measuring micrometers

2 optical fibers connected to a PC

Wood box laid on a stable table



PC of acquisition

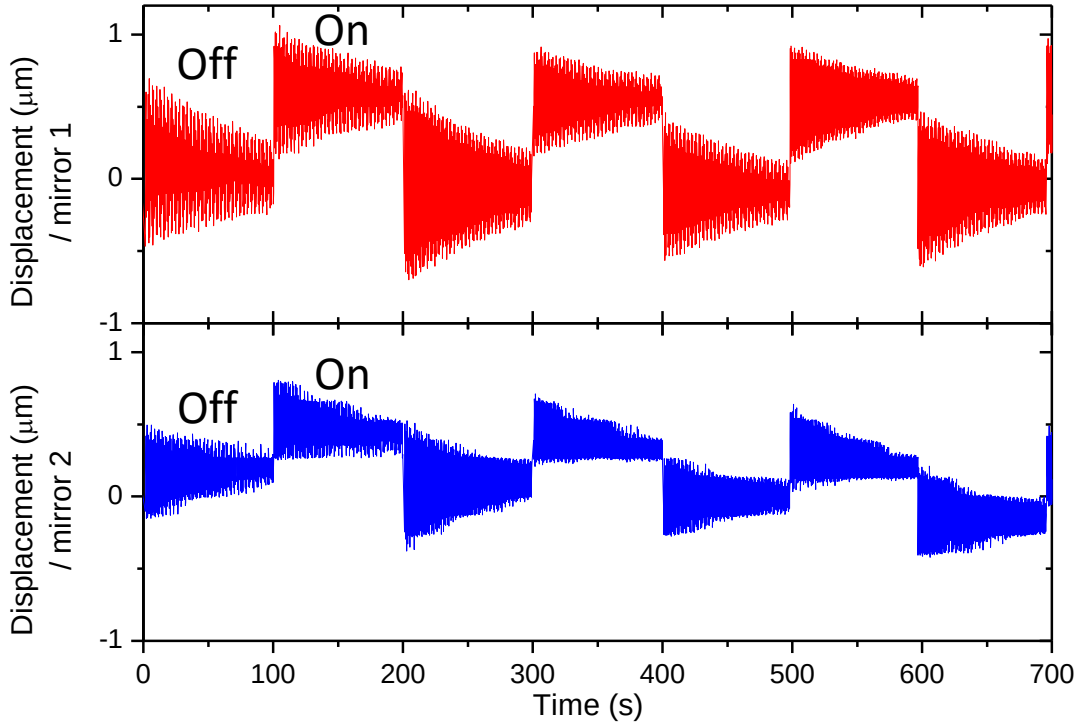


Coil-Disc device hang in a wood box

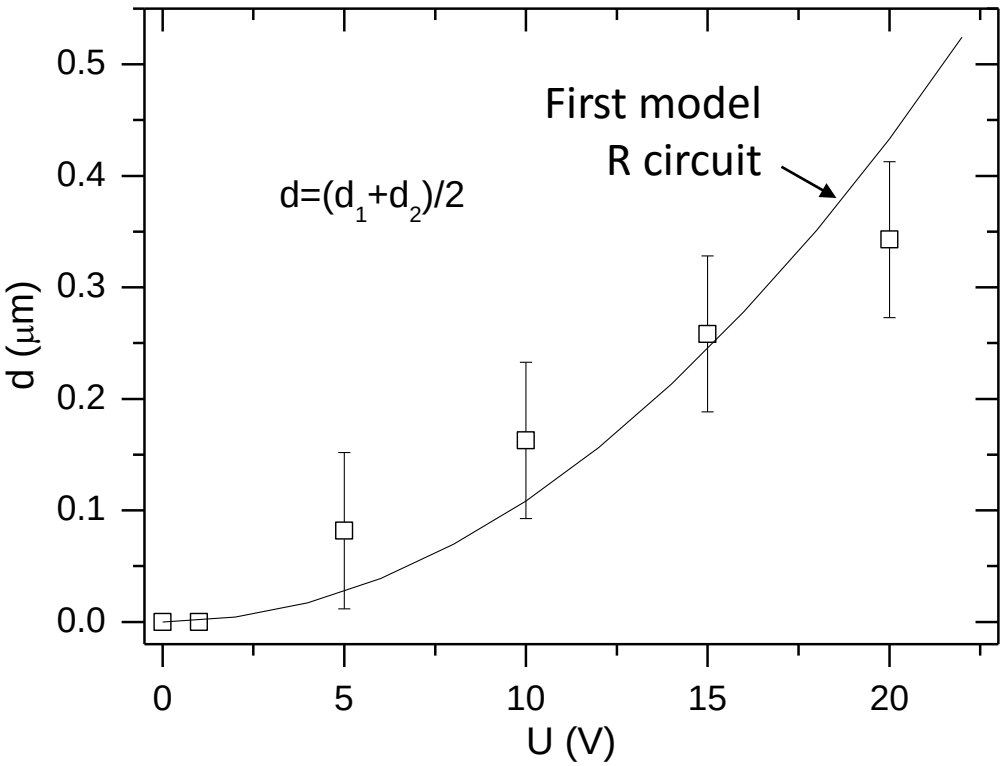
http://dscharrier.free.fr

Results

Measurement of displacements with 100 s On/Off generator voltage sequences (20 V – 15 MHz)



Averaged displacements at 15 MHz

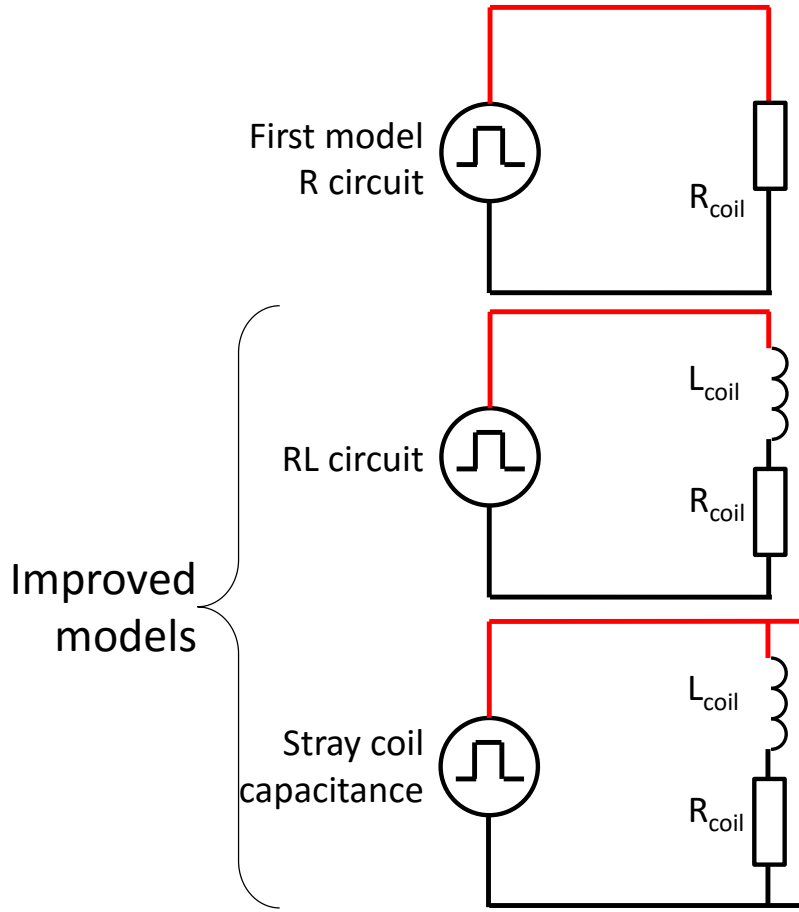


A damping of pendulum is visible after an On or Off sequence.
Drift lower than 0,2 μm over 700 s was observed on the whole setup.

D.S.H. Charrier, Micronewton electromagnetic thruster, Appl. Phys. Lett. 101 (2012) 034104. doi:10.1063/1.4737940.
D.S.H. Charrier, Erratum: “Micronewton electromagnetic thruster”, Appl. Phys. Lett. 105 (2014) 149902. doi:10.1063/1.4897969.

Force calculations

- Different configurations of impedance circuits were used to calculate the current in the force equation $F_{disc} = \frac{1}{t}\int_0^{r_2}\left(2\pi r B_{\rho 1} \int \vec{B}_{z1} d\vec{S}_2 / L_2\right) dr$



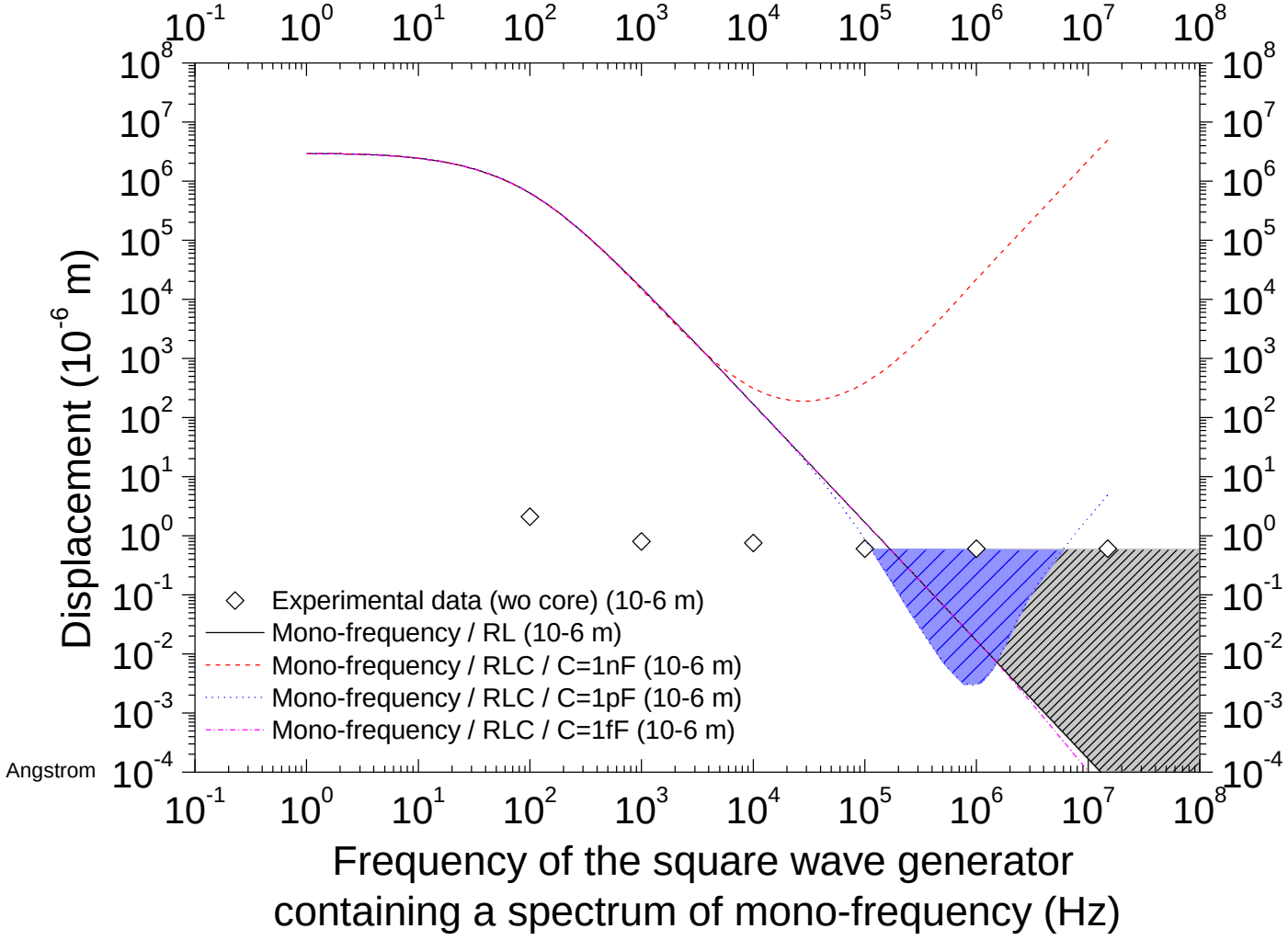
$$i_{Rcoil}(t) = \frac{U(t)}{R_{coil}}$$

$$i_{RLcoil}(t) = \frac{U}{R_{coil}}\left(1 - exp\left(-\frac{t}{\tau}\right)\right)$$

$$Z_{RLCcoil} = \frac{\left(R_{coil}^2 + L_{coil}^2\omega^2\right)\left[R_{coil} - j\omega\left(C_{stray}R_{coil}^2 + C_{stray}L_{coil}^2\omega^2 - L_{coil}\right)\right]}{R_{coil}^2 + \omega^2\left(C_{stray}R_{coil}^2 + C_{stray}L_{coil}^2\omega^2 - L_{coil}\right)^2}$$

Onset frequency

❖Calculated displacements with different impedance models



Onset frequency at circa 170 kHz in case of RL equivalent circuit

Conclusions

- Energy emitted by the coil is partially converted into a force in the coil-disc device: proof-of-concept is shown.
- First analytical model was proposed with a simple R circuit but showed discrepancies between calculations and experimental data until one order of magnitude.
- Improved RL impedance equivalent circuit has been built and has shown a onset frequency at 170 kHz. Therefore further investigations need to take into account the different EM frequencies involved in the device.
- If existing, stray capacitance C from the coil should be much below 1 nF.
- A complete model should take into account the Joule heating (black body emission) coming from eddy currents in the disc. Possibly, finite element analysis is required for a better description.

Acknowledgements

- ‘Flying Circus of Physics’ book by Jearl Walker for having inspiring this work. Think out of the box!

- French CPER and Région Poitou-Charentes for post-doc funding.

- APS committee for having accepted the abstract for a talk.