AO@SW with Vrala: Simulations and Tests

The Actuator Design and the Experimental Tests of a New Technology Large Deformable Mirror for Visible Wavelengths Adaptive Optics

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Outline

Outline

Vrala

Del Vecchio
et al.

Matching new science and new ELT discoveries

The Synergies

- Starting from:
  - Possible and qualified synergies between ELTs and 8-m telescopes working at similar spatial resolution
- Given:
  - the telescope resolutions
  - the extensive use of AO on both classes
- The idea is:
  - *visible* AO at 8-m telescopes to match λ/D:

$$\frac{2.12e-6}{42}\,(\mathrm{ELT}) \approx \frac{.7e-6}{8}\,(\mathrm{AO@SW})$$

- Looks promising:
  - The AO@SW simulations investigate this possibility [Agapito et al., 2012]

Outline

Basic Requirements of High Order DM's

The Specs are very Severe

rms force (turbulence correction)	.363 N
max force (static)	.36 N
max force (dynamic)	1.27 N
stroke (usable)	$\pm$150 μm
stroke (mechanical)	$\pm$200 μm
bandwidth	2 kHz
typical inter-actuator spacing	25 mm
typical actuator length	$\leq$ 60 mm
typical mover mass	$\leq$ 10 g

DM Stiffness vs. DM Thickness & Act Spacing

The Plate Stiffness is Strongly Non-Linear

The plate stiffness

$$K_{flex} \propto t^3 \times (1/d)^4$$

t = thickness d = dimension

- What if
  - the inter-actuator spacing is slightly reduced
  - the thickness is slightly increased

$$\left.\begin{array}{ll} \text{HIGHER ORDER DM} & d = 30 \rightarrow 25\,\text{mm}\ (16\%) \\ \text{TICKER DM} & t = 1.6 \rightarrow 2\,\text{mm}\ (20\%) \end{array}\right\} \rightsquigarrow 2 \times K_{flex}$$

Efficiency is crucial

Vrala

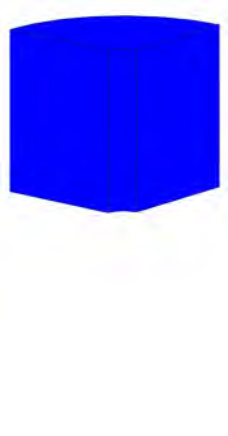
Del Vecchio et al.

Rationale
Background
Design Drivers
Statics
Approach
Results
Freq.-Domain
Time-Domain
Control System
Closed-Loop
Prototype

Outline

The Electromagnetic Core

Variable Reluctance LM: $F = \int_S -\frac{1}{2}\left(\mathbf{H}\cdot\mathbf{B}\right)\mathbf{n} + \left(\mathbf{n}\cdot\mathbf{H}\right)\mathbf{B}^T \, dS$



[Del Vecchio et al., 2010]

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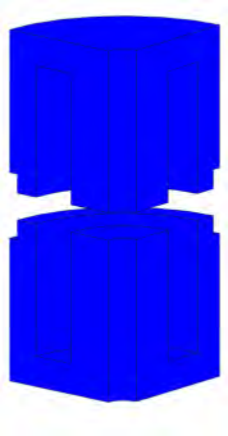

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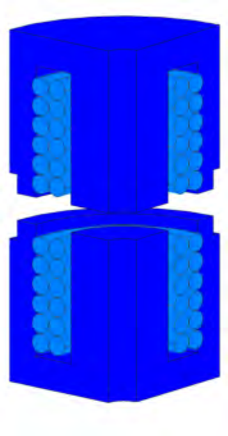

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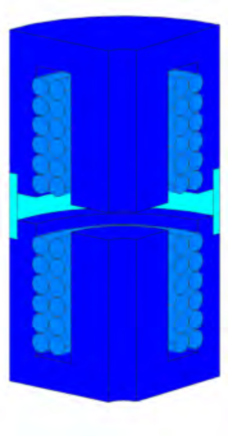

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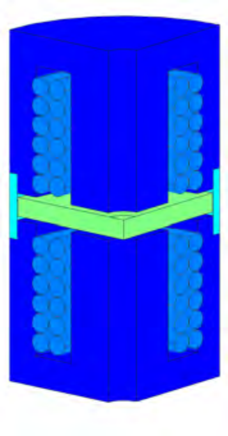

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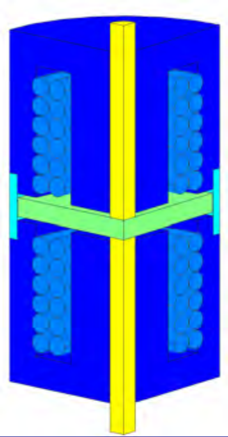

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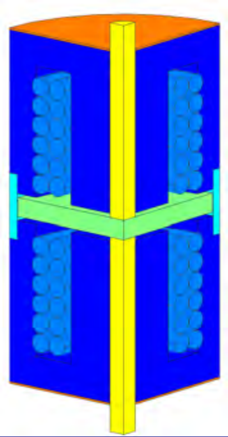

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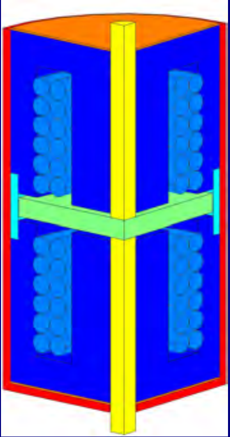

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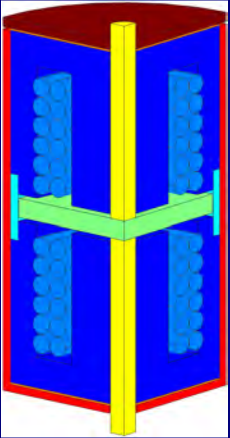


[Del Vecchio et al., 2010]

Outline

The Efficiency

Optimizing the Geometry to Get good Performances

$$\varepsilon = \kappa(I)\frac{\varphi W_{coil} H_{coil}}{\rho 2\pi R_{coil}}$$

$$F = \kappa(I)\,(NI)^2$$

- Constraints
- Parameters

ϵ

$4.65\,\mathrm{N} \times \mathrm{W}^{-1}$

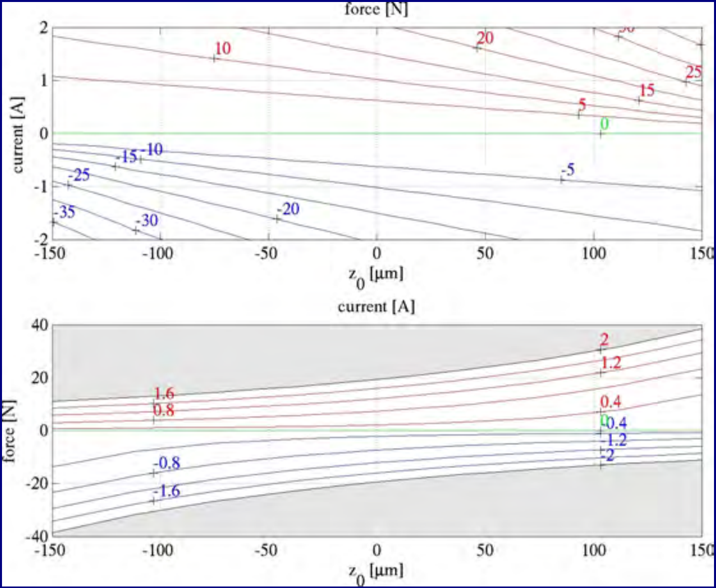
wire outer radius	120.0 μm
insulation thickness	10.0 μm
outer radius of stator	7 mm
inner radius of stator	1 mm
height of stator	7.5 mm
height of stator slot	5.9 mm
gap height	.2 mm
outer radius of mover	6.95 mm
inner radius of mover	0 mm
thickness of mover	1 mm
height of coil slot	5.9 mm
width of coil slot	2.3 mm
mean radius of coil slot	4.62 mm
filling factor	.627

The Force Function

Running the Magnetostatics to Get $F = f(z, I)$

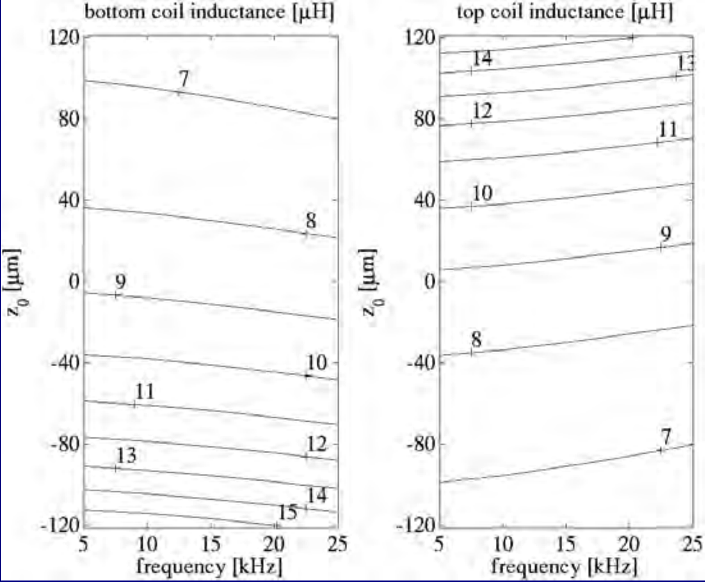
Vrala

Del Vecchio et al.



Measuring the Displacement

Getting the Function $L = f(z)$



The Governing Equation

Selecting the Proper Damping

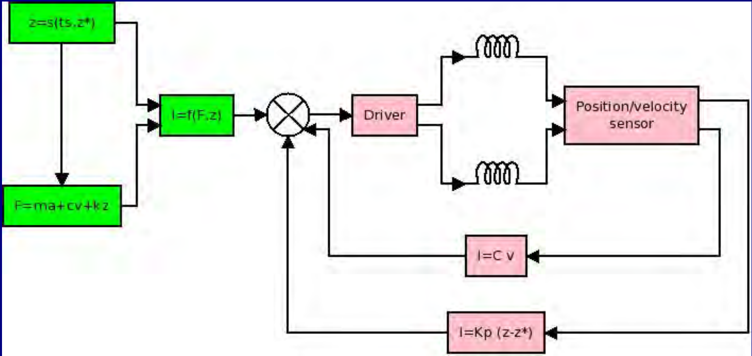
- $F = \frac{d^2z}{dt^2} + 2\zeta\omega_0\frac{dz}{dt} + \omega_0^2 z$
  - $\zeta = \frac{c}{2\sqrt{K(M+m_0)}}$
  - $\omega_0 = \sqrt{\frac{K}{m_0 + M}}$
- z mover position
- K mirror bending stiffness
- m_0 mirror mass per actuator
- M mover & shaft mass

$\zeta = 1$ avoids oscillations without loosing fastness

Outline

A Simple Design

A Preshaping-based Control Logic ⊕ a *Sniffer*-based Control Electronics



Open Loop

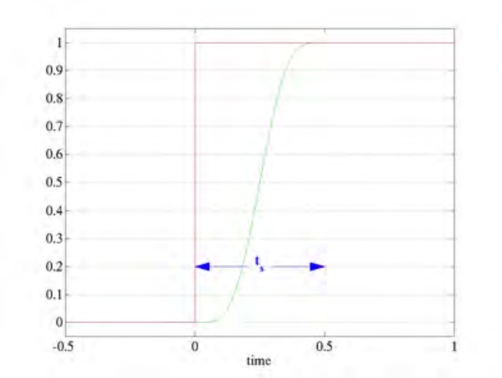
set point — *smoothed Heaviside step function*
macro dynamics — *2nd-order system*
pre-shaper — *look-up table* $I = f(z, F)$

Closed Loop

sniffer — *feedback z sensor,* $z = f(L)$
driver — *current command*

A Simple Design

A Preshaping-based Control Logic ⊕ a *Sniffer*-based Control Electronics



Smoothing

Replace the non continuous step function with the smoothed Heaviside step function, a polynomial continuous up to the n-th derivative

A Simple Design

A Preshaping-based Control Logic $\oplus$ a *Sniffer*-based Control Electronics

S/W key features

The rising time $t_s = .5 \times 10^{-3}\,\mathrm{s}$ is an input

A very simple PD feedback control through the open-loop command (*pre-shaping*)

H/W key features

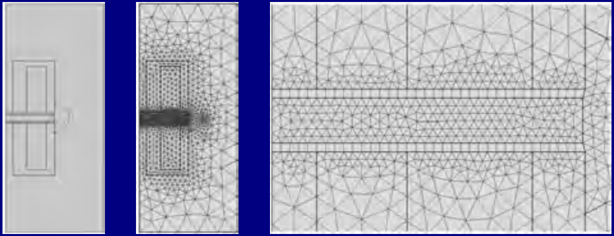
The sniffer is a processor that acquires the voltage of the inductors, performs some computational tasks and infers the displacement

Driver and sniffer embedded in the same electronic board

Outline

The Ale

How the Moving Mesh Works



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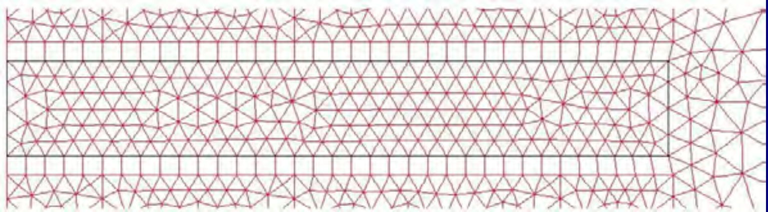

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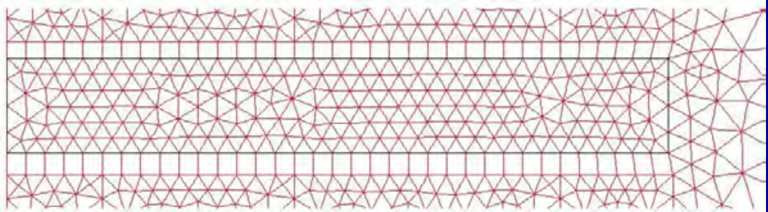

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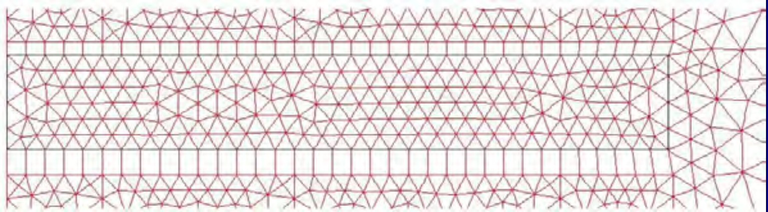

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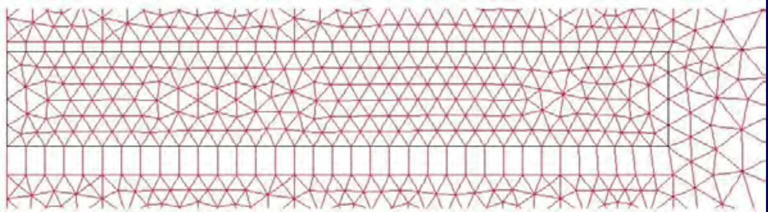
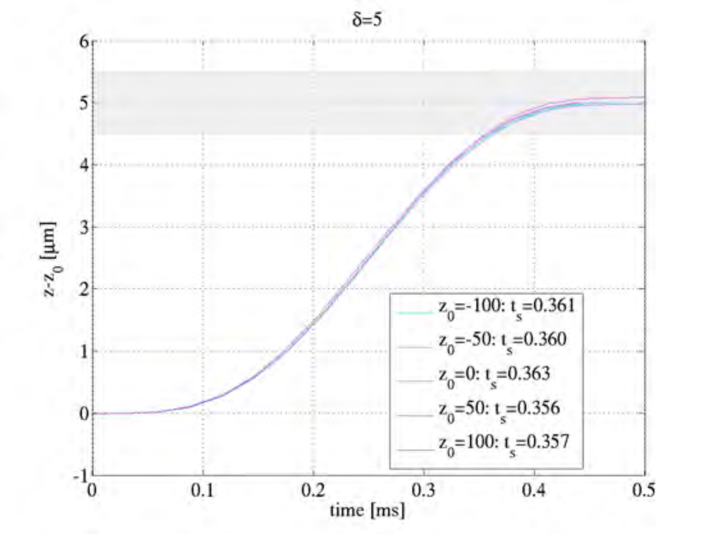
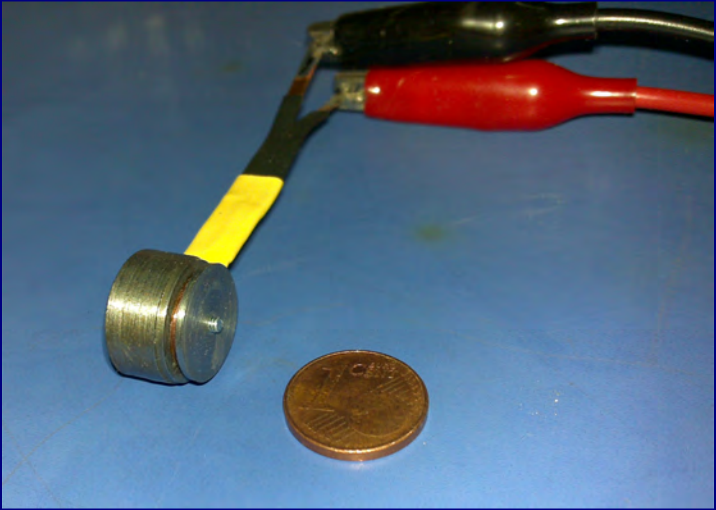


A Severe Requirement
The Results of the Smart Solution



Validating the Magnetostatics

The Preliminary Prototype



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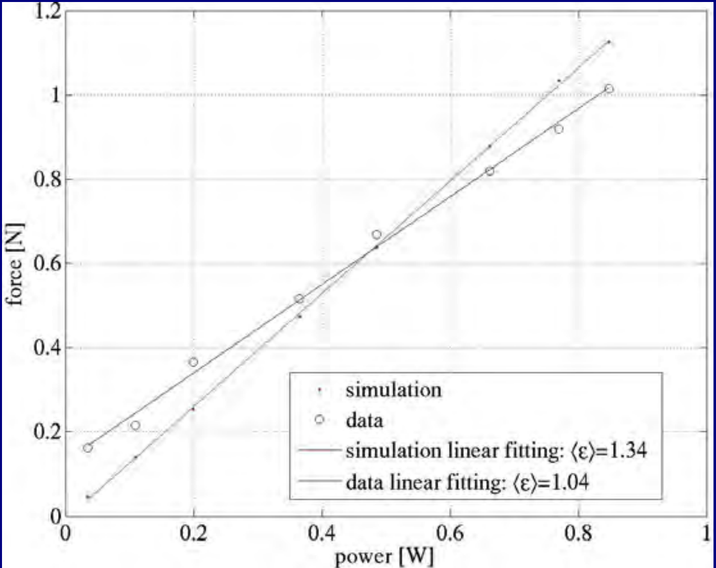

Lessons Learned & Future Work

A challenging project

Applying AO@SW corrections on a high-order, long-stroke, very large DM requires very large forces and unprecedented actuator densities

- Simple and very effective magnetic circuit
- All-in-one control electronics
  - position sensor
  - current driver

Lessons Learned & Future Work

- The actuator can accomplish the demanding specifications with
  - $\epsilon = 4.65\,\mathrm{N} \times \mathrm{W}^{-1}$ $\rightarrow$ **low power dissipation**
  - $t_s = .37\,\mathrm{ms}$ for $\delta = 5\,\mu\mathrm{m}$ $\rightarrow$ **high speed**
  - $\Phi = 15\,\mathrm{mm}$ $\rightarrow$ **small separations**
- The numerical results are (statically) verified by a very simple, preliminary prototype

Lessons Learned & Future Work

- Alternative coil
  - round wire $\longrightarrow$ strip $\Rightarrow$ $\varphi = .627 \hookrightarrow .95$
- Further computations
  - closed loop frequency response
  - more refined multiphysics
  - 3D modeling
- Complete prototype + 4×4 demonstrator
  - possible construction issues
  - closed loop response
  - power dissipation
    - passive convective cooling?
    - without any Reference Body?

For Further Reading I

Agapito, G., Arcidiacono, C., Quiros-Pacheco, F., Puglisi, A., and Esposito, S. (2012).
Infinite impulse response modal filtering in visible adaptive optics.
In Ellerbroek, B. L., Marchetti, E., and Véran, J.-P., editors, *Adaptive Optics Systems III*, volume 8447 of *Proc. SPIE*. SPIE.

For Further Reading II

Del Vecchio, C., Marignetti, F., Agapito, G., Tomassi, G., and Riccardi, A. (2010).
Vrala: Designing and prototyping a novel, high-efficiency actuator for large adaptive mirrors.
In Ellerbroek, B. L., Hart, M., Hubin, N., and Wizinowich, P. L., editors, *Adaptive Optics Systems*, volume 7036 of *Proc. SPIE*. SPIE.