

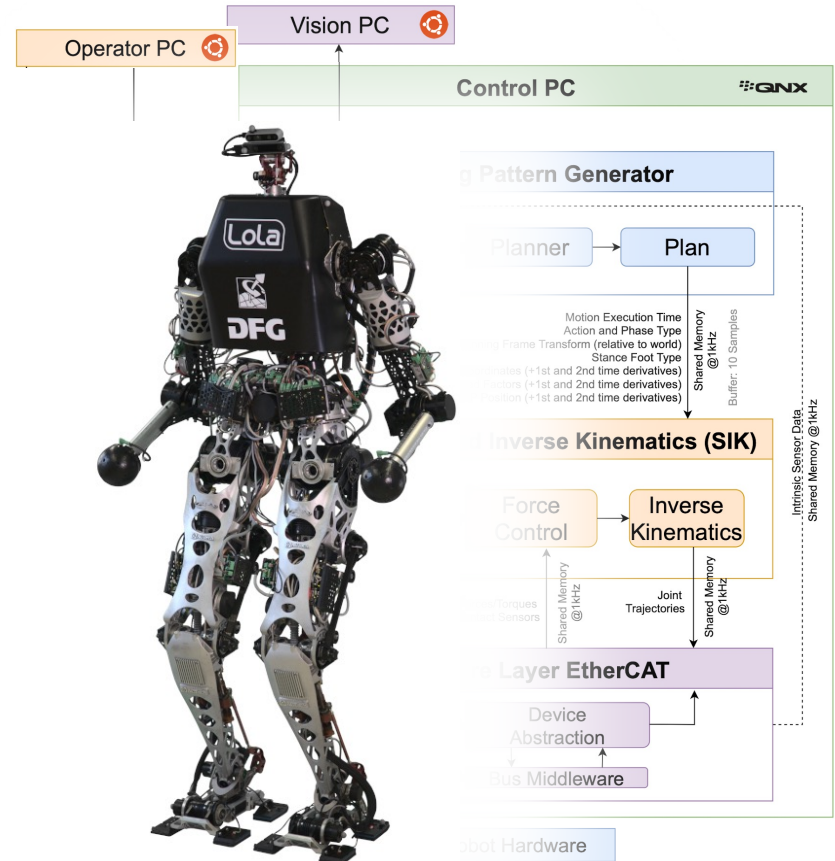
# LOLA and the Forbidden Fruit

Development of Direct-Drive Actuators  
 for Humanoid Robotics

**Tomas Slimak**  
 Michael Piltz



Dynamic Walking



# Who needs direct-drive?



Time: 1.14s

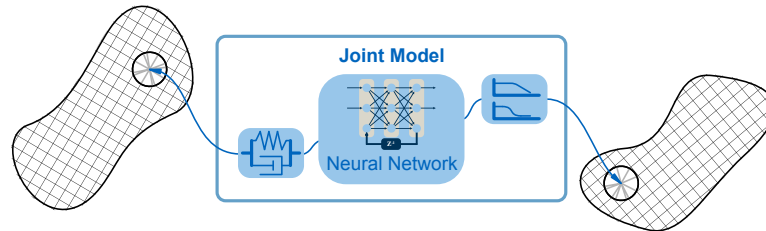
Chair of Applied Mechanics, TUM

# Motivation

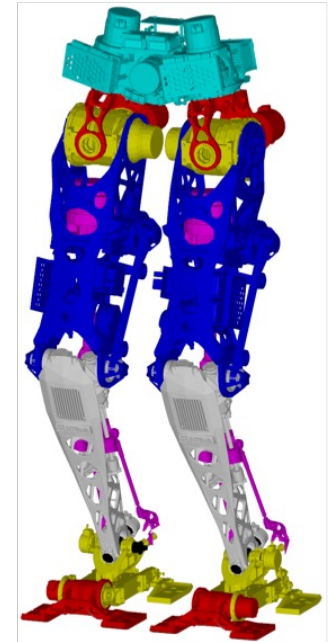
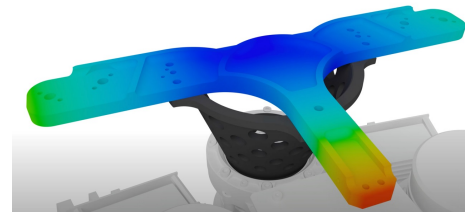
## New (kinda) flexible torque-controller legs

Harmonic drives suck

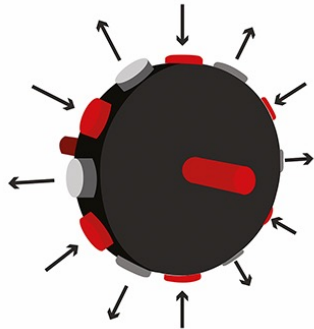
- Inefficient
- Expensive
- “Fragile”



Virtual stiffness & swinging relies on high controller bandwidth

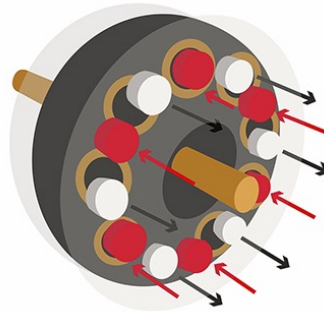
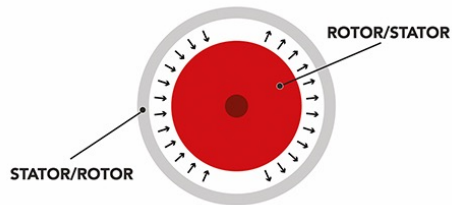


# Axial Flux Motors



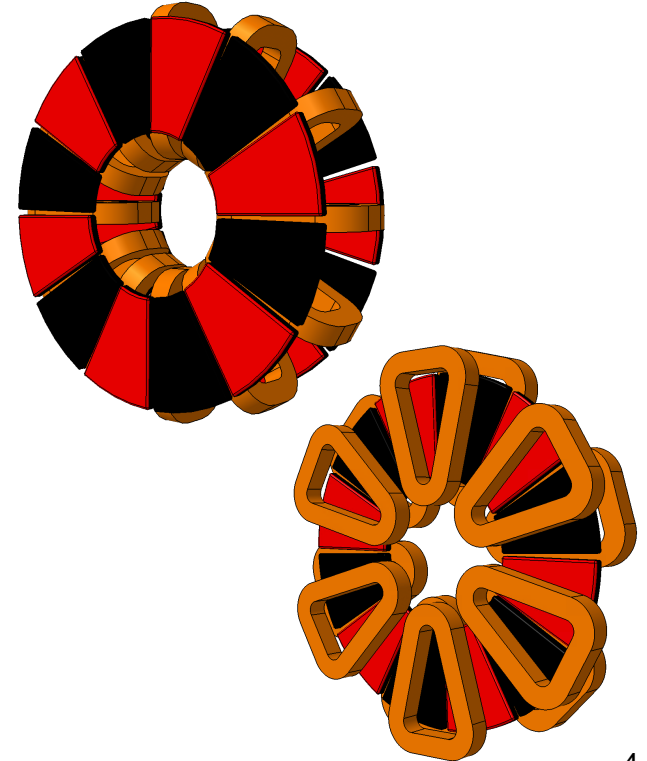
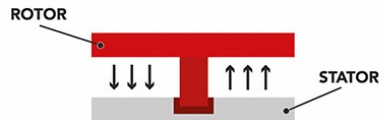
**RADIAL FLUX**

*Flux is produced radially along the sideways of the rotor*



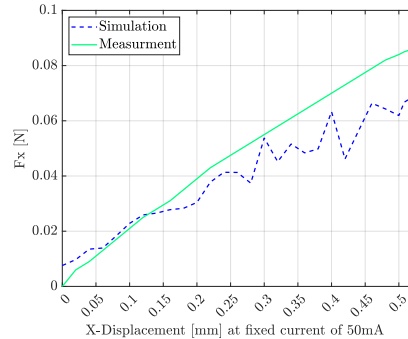
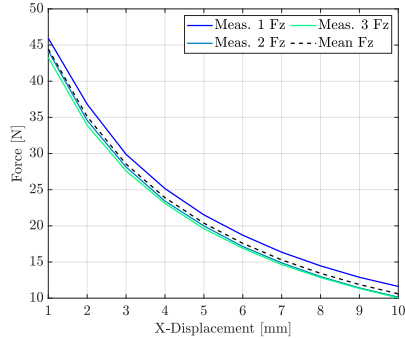
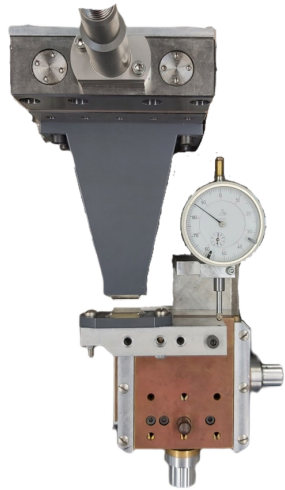
**AXIAL FLUX**

*Flux is produced axially along the axis of the rotor*

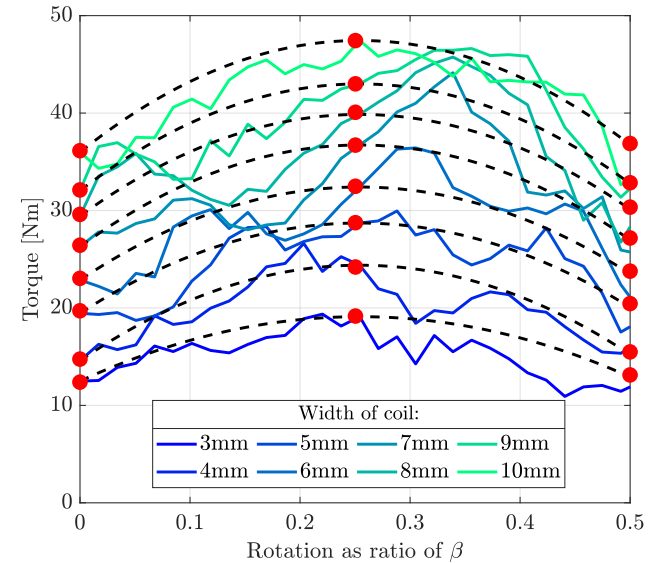


# Validation & Reduction

1-10% NRMSE

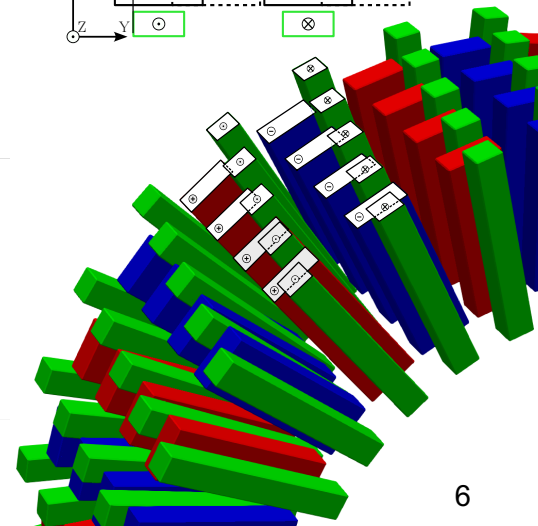
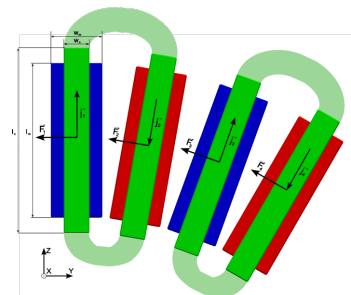
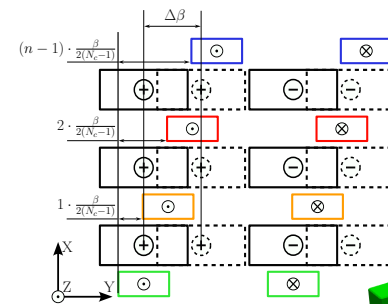
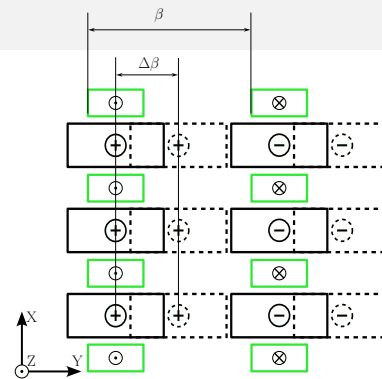
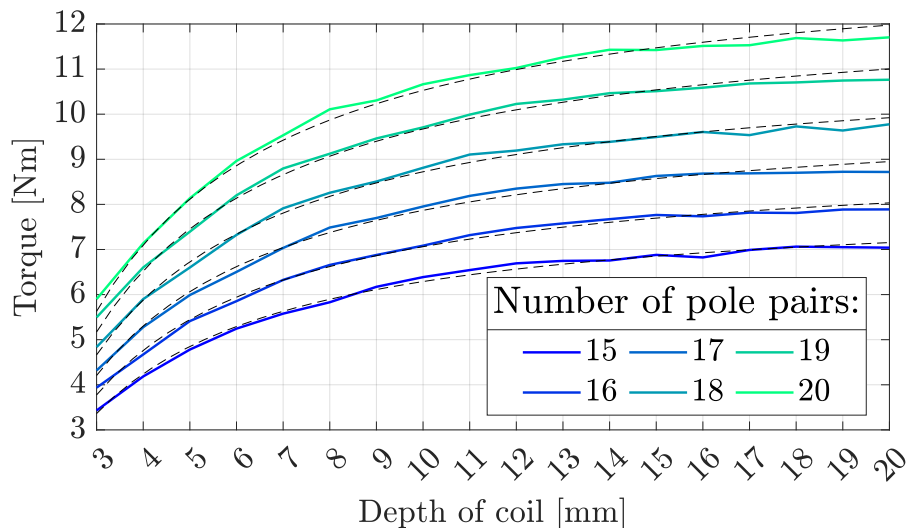


Full Simulation 8,000,000 DoFs  
+30mins & 128GB RAM



# Parameter Studies

## Magnet and coil dimensions + arrangement



# Optimization + Outlook

## Evolutionary Algorithm

$$K = K_{mass} \cdot \frac{m}{m_{ref}} + K_{torque} \cdot \frac{|T_{xref} - T_x|}{T_{xref}} + K_{radius} \cdot \frac{R_{max}}{R_{ref}} + K_{length} \cdot \frac{l_{AFPM}}{l_{ref}}$$

24 Hours on 16 Core 6GHz 128GB RAM

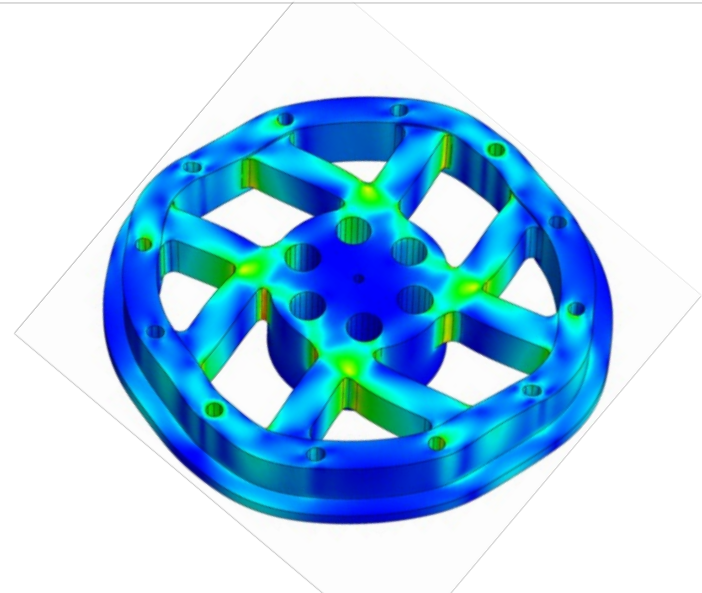
Result: ~50Nm @  $\varnothing$ 180mm × 50mm

**Endless improvements possible**

Gradient-based optimization

Magnetic saturation & hysteresis

Temperature effects



# Thank you for your time

I'd be happy to answer any questions you might have

## **LOLA and the Forbidden Fruit**

Tomas Slimak

Dynamic Walking 2023