



**INNOVATING
TOGETHER
FOR SUPERIOR
MACHINES**

High Dynamic Linear Motor

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FLANDERS' MECHATRONICS TECHNOLOGY CENTRE

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Content

- + **Intro**
- + **High dynamic linear motor**
 - General principal linear motor
 - Chosen architecture
 - Challenges
 - Energy efficiency
- + **Conclusion**

FMTC in short

+ Flanders' Mechatronics Technology Centre

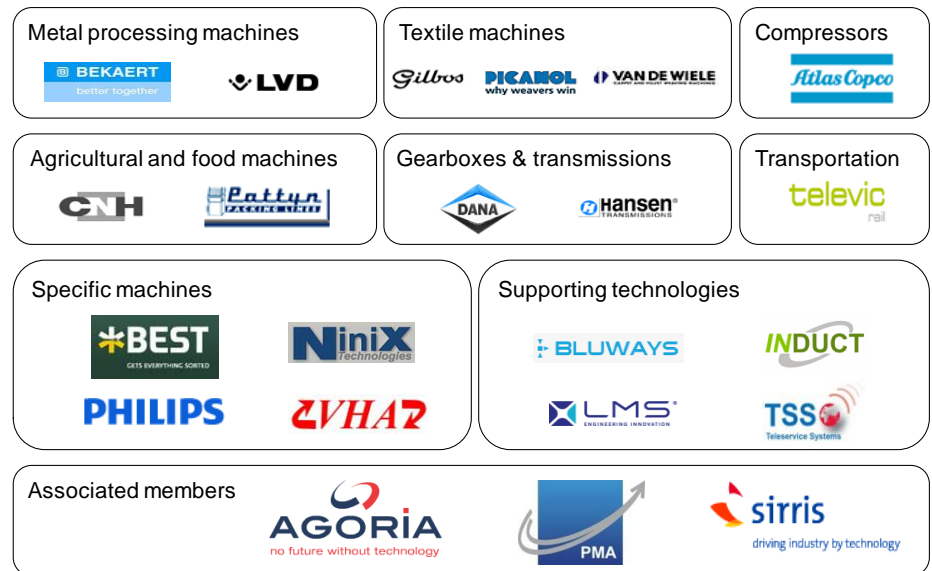
- Research center (~30 employees)
- Based in Leuven

+ Member organization

- Companies in machine construction or mechatronics sector with research activities

+ Mission:

- Jointly develop new and improve existing generic mechatronic competences and technologies to improve the competitive edge of its member companies



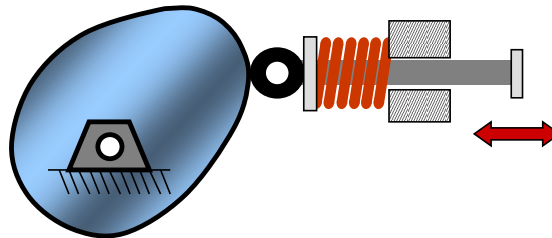
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- + **Intro**
 - High dynamic linear motions
- + **High dynamic linear motor**
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Linear motions

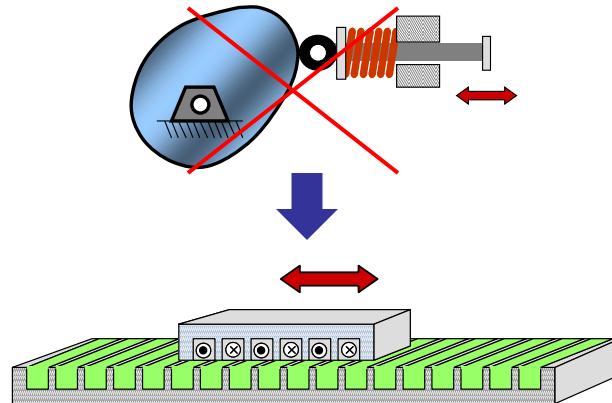
+ Generation:

- Typical:
- Mechanical mechanisms
 - cam, crank, other mechanisms, ...
- **Reliable, mature**
- **No flexibility**
 - adaptation of motion profile = mechanical adaptation



Linear motions

+ Direct drive solution (i.e. linear motor)



- **Flexibility**
 - Easily adapt motion profiles
 - Electronically controlled
- **Compactness**
 - Better integration in design possible
- **High accuracy possible**

High dynamic linear motions

- + **FMTC-project:**
 - high dynamic linear actuators
 - High accelerations
 - low moving masses
 - low external forces
- + **Industrial requirements**
 - **High Accelerations:** 2000-3000 m/s²
 - **Long strokes:** 250 – 3000 mm
 - Speed: 5 to 30 m/s
- + **→ Not available on market**
 - Investigate custom design

Content

+ Intro

- High dynamic linear motor

+ High dynamic linear motor

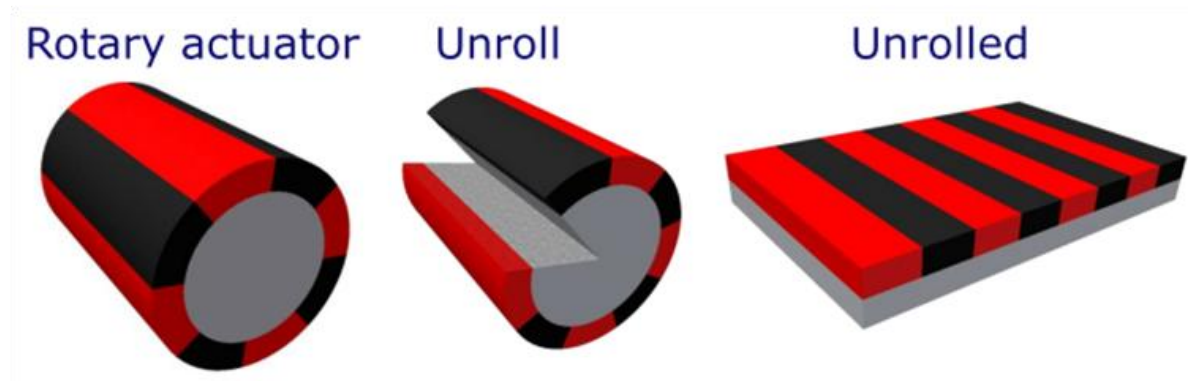
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General principle

+ Linear electric motor

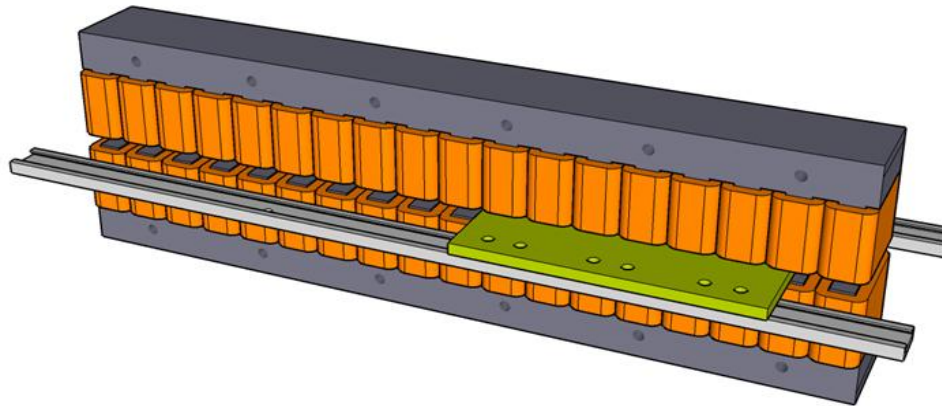
- Similar principle as rotary motor
 - Unrolled stator and rotor



Picture: ir. Koen Meessen 'Tubular Permanent Magnet Actuators' TU Eindhoven

Architecture (1)

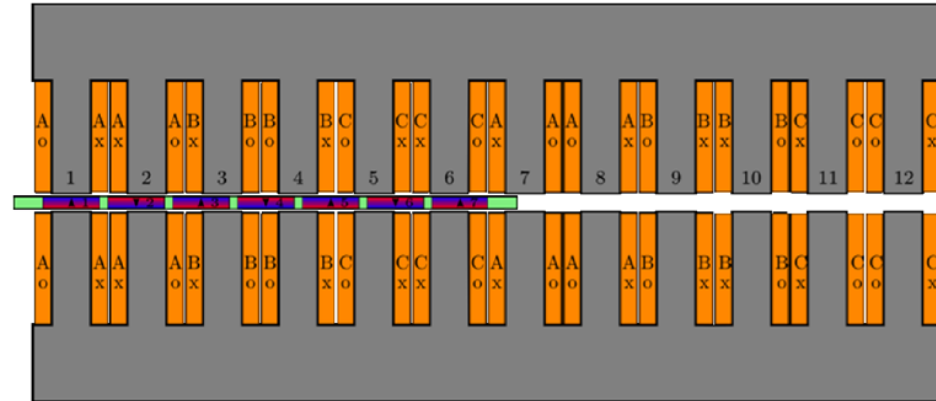
- + **Moving magnet actuator**
 - Moving permanent magnets
 - Embedded in slider
 - Slider moves on rail
 - Double stator
 - 3 phase steering
 - Coils on 'fixed' stator



Architecture (2)

+ Main advantages:

- No moving wires
 - Lifetime ++
- Thermal
 - Coils in contact with stator
→ heat dissipation ++
- High force/mass ratio
 - High accelerations feasible



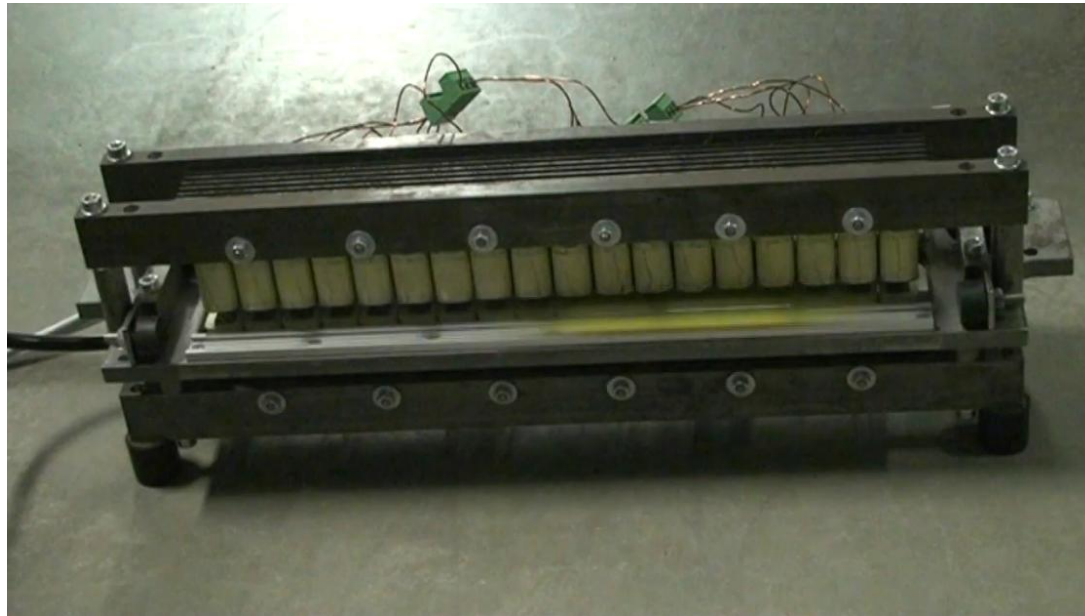
+ Design

- Prototype based on (magnetic) FE
 - Designed for 2000 m/s² acceleration, 25 cm stroke
But potential for more
 - Analysis of all relevant parameters
Dimensions, different slot/pole ratios, ...

Prototype

+ Movie

- Stroke 20 cm, 10 Hz motion



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 - Cogging
 - Position tracking
 - Control
 - Guiding
 - Energy efficiency
- + **Conclusion**

Challenges

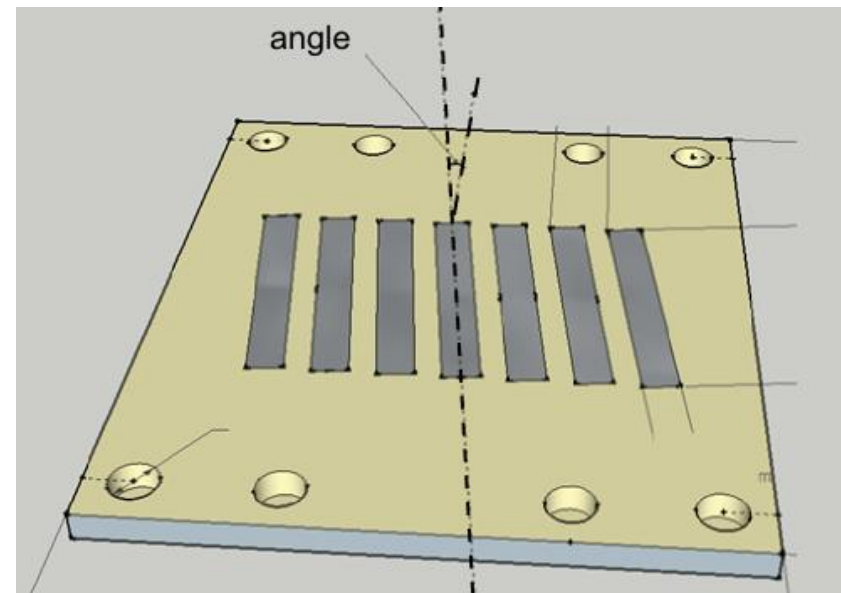
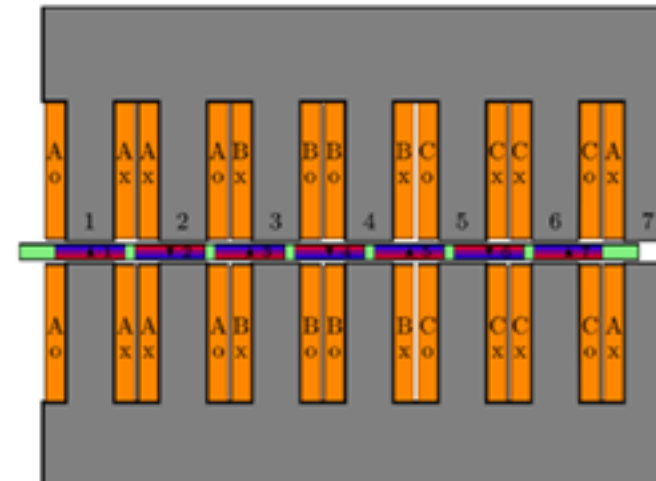
cogging force

+ Cogging force

- 'passive' ripple force
- Caused by attraction to slots
- Inherent to our architecture
- Effect on position accuracy

+ Cogging reduction

- Rotate magnets
- ripple force
 - Reduced with ca. 60-70 %
- → No need for electronic compensation



Challenges

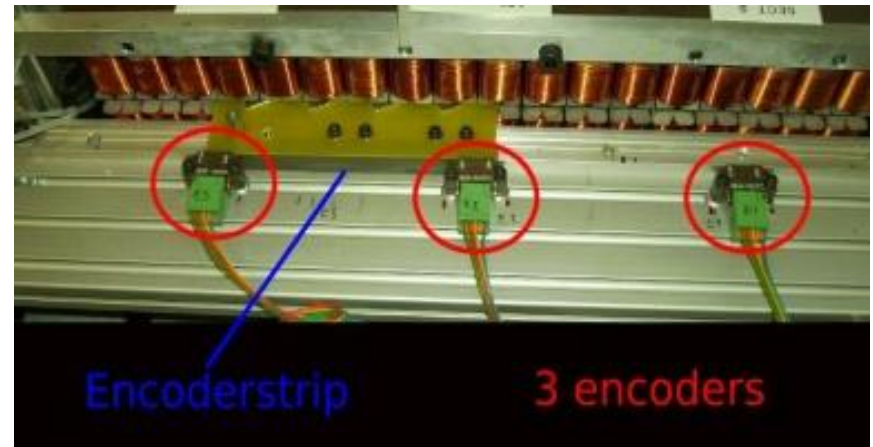
position tracking (1)

+ Position tracking

- Measure position slider
 - Long stroke
 - Low moving mass
- Cheap sensors

+ Solution

- Optical encoders
- Moving codestrip on slider
- Multiple encoders on stator
- Cheap solution for 20 μm accur.
- Algorithm needed to combine multiple signals



Sensor algorithm:

Measure long stroke with high accuracy



Challenges

position tracking (2)

+ Position tracking algorithm

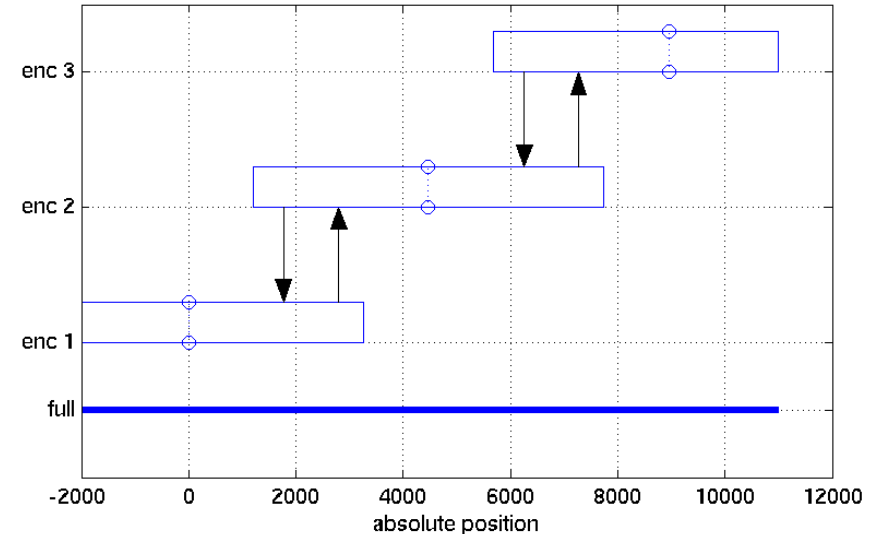
- Combine different sensors
- Generate 1 'master' signal
- 'Glue logic'

+ Implementation

- Very fast processing required
- Implemented on FPGA

+ → position measurement

- Low moving mass
- Cheap
- scalable to longer strokes



Challenges

Control

+ Control

- PI-controller not accurate enough
 - high dynamic motions
 - → learning controller required
- feedback + feedforward + Repetitive learning
 - FMTC toolbox

+ Advantages repetitive learning

- Very high position accuracy
- Can compensate time varying effects
 - Ex. wear

+ Experimental results:

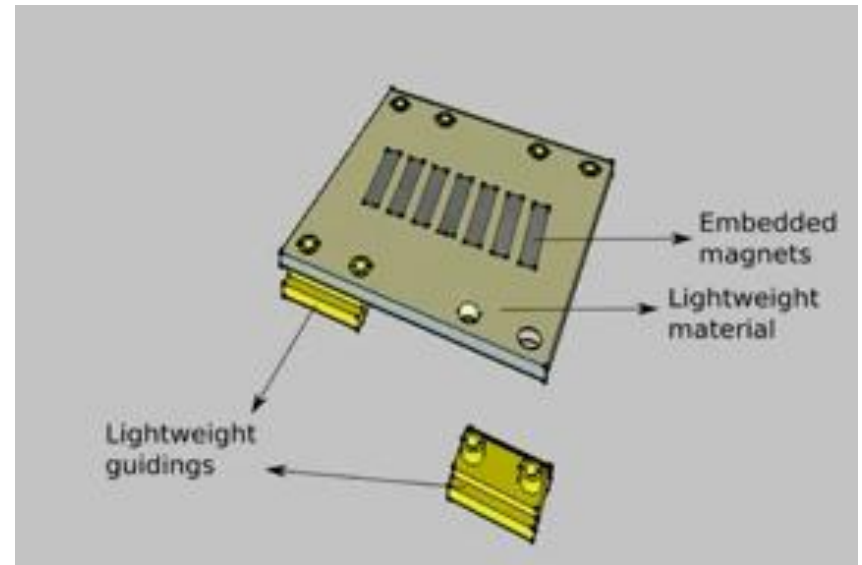
- Excellent position accuracy
 - < 0.1 mm @ 100g, stroke > 200 mm

Challenges

Guiding

+ Guiding

- Requirements:
 - Withstand high acceleration and speed
 - Low mass
 - High precision + withstand normal forces
 - Low friction
- Choice:
 - dry guiding
 - guiding elements attached to moving structure
 - Slider moves on rail



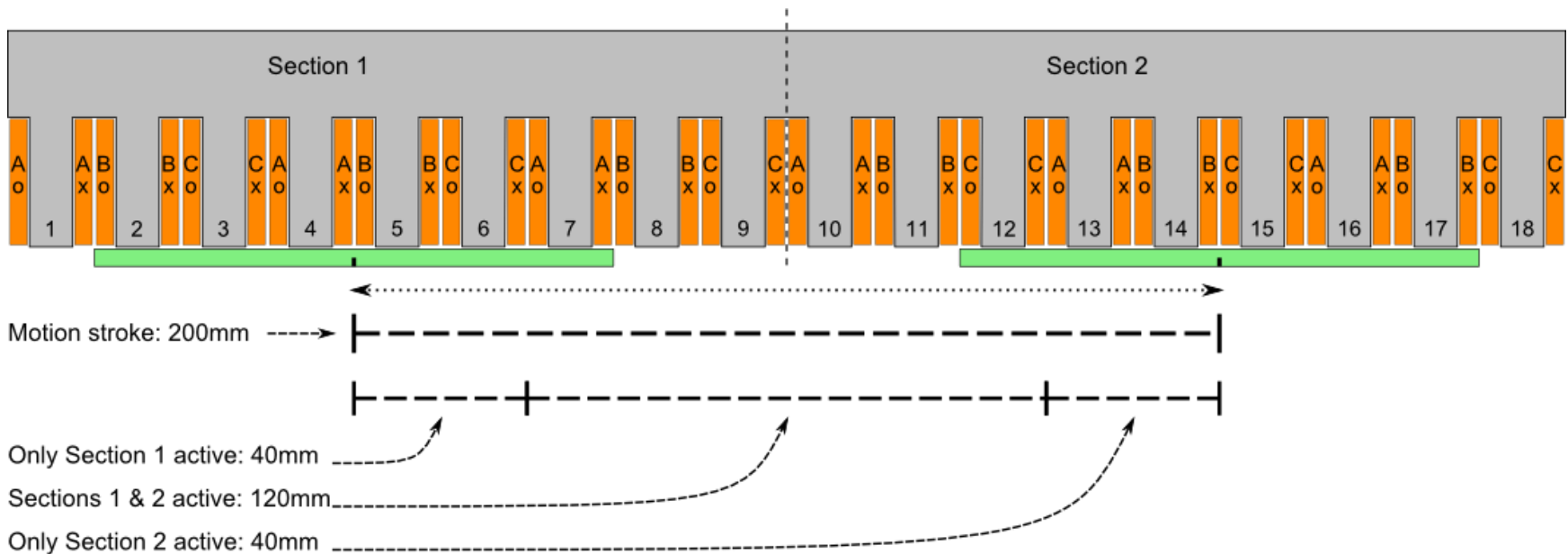
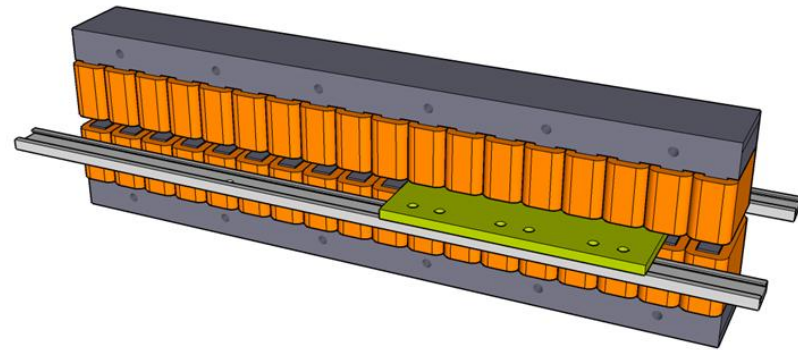
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Energy efficiency (1)

+ Idea

- Shutdown useless coils
- Only activate coils around slider
 - Split coils in a number of sections



Energy efficiency (2)

+ Advantages

- Better energy efficiency
 - No current = No copper and iron losses
 - Energy consumption:
 - > 30 - 60 % reduction
 - depends on architecture / number of sections
- Improved motor dynamics
 - Better electrical dynamics
 - Desired current in coils is reached faster

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Conclusions

+ Feasibility demonstrated!

- Accelerations of 200g demonstrated
 - Potential for more
- Design can be extended for longer strokes
- Challenges were tackled
- Costeffective
 - No expensive components were used

Conclusions

+ More info:

- [Movie: http://www.youtube.com/user/FMTCvzw#p/u/6/HFnqcvSHrXc](http://www.youtube.com/user/FMTCvzw#p/u/6/HFnqcvSHrXc)
- info@fmtc.be

+ Questions?



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