EDRIVE - MEC

EPSRC Supergen Marine

Grand Challenge

1st April 2016 – 31st March 2019

Industrial Advisory Board 2018 meeting

1145-1245 Thursday 14th June 2018 (Day 3 at ICOE)

Cunard Room, in the upper part of la Cité

Agenda 2018

- Welcome & Introductions (Simon)
- Work-package updates
  - Electromechanical Development, Magnetic Gearing Systems, Power Converters and Control (Nick)
  - Wave to Wire Modelling (Richard)
  - Technology Roadmap (Simon)
- Future development discussion (All)

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SUPERGEN GRAND CHALLENGES

Today's meeting objectives

1. To engage with industrial partners to ensure outcomes are well aligned to the needs of the marine energy industry.
2. Review progress to date and next steps for each project work package.
3. Identify follow on project opportunities and what the Industrial partners think would be good.

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SUPERGEN GRAND CHALLENGES

E-DRIVE Aim

Develop an integrated electrical power take off system with non-mechanical speed enhancement, integrated and reliable flexible power electronics, providing adaptive control over a range of operating regimes, taking into account nominal and extreme load conditions.

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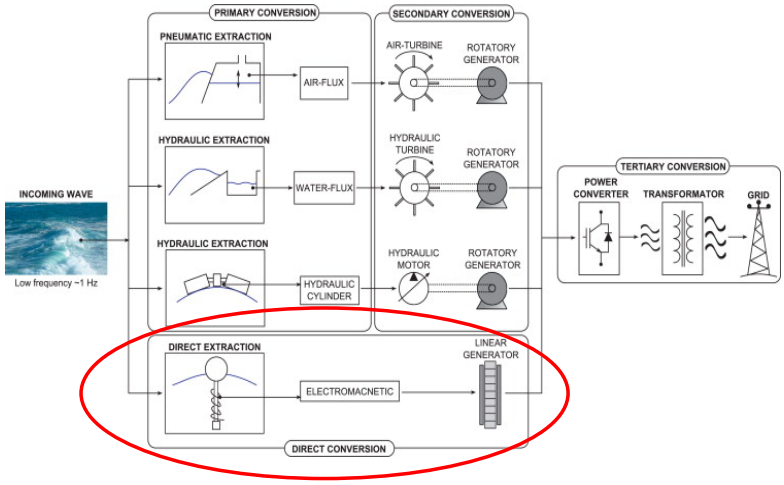
PTO Options



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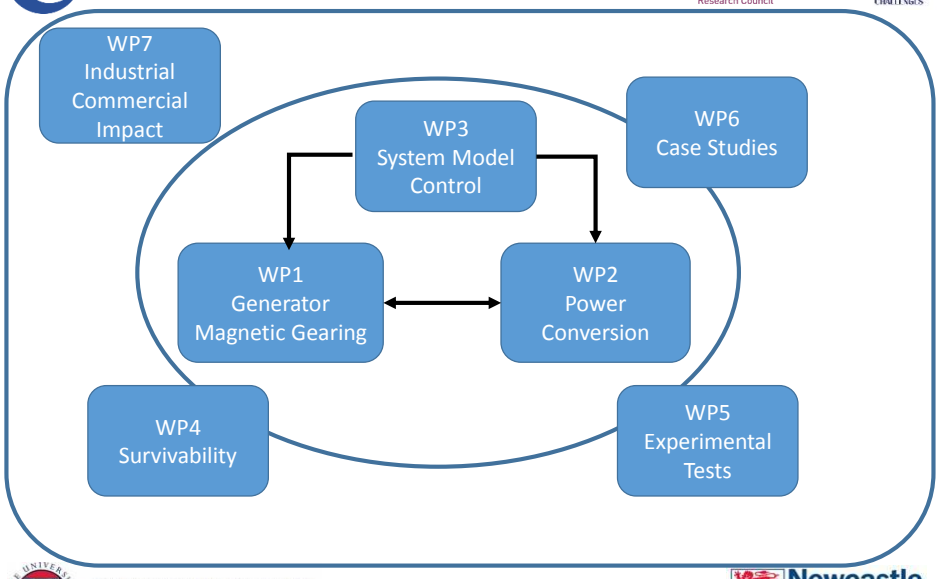
WP Overview



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Academic Partners

- University of Edinburgh
  - Markus Mueller, Aristides Kiprakis, Henry Jeffrey
  - Richard Crozier, Simon Robertson, Ben McGilton (PhD)
- University of Newcastle
  - Nick Baker, Volker Pickert, Steve McDonald
  - 2 PhDs
- TU Delft
  - Henk Polinder
- Universidad de Chile
  - Roberto Cardenas
- UNAM, Mexico City
  - Rodolfo Silva Casarin

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Agenda 2018

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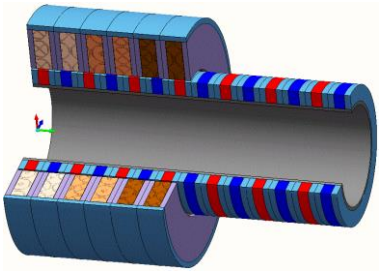
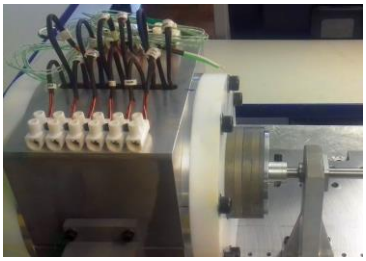
SUPERGEN GRAND CHALLENGES

General Linear generator development

- High force or Torque Density
- Tend to use permanent magnet machines





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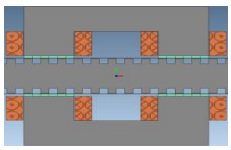
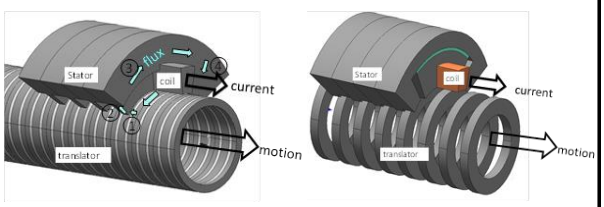
SUPERGEN GRAND CHALLENGES

General Linear generator development

- Capital cost driven by magnet mass
- Use topologies with efficient magnetic circuit
- Alternative topologies being designed





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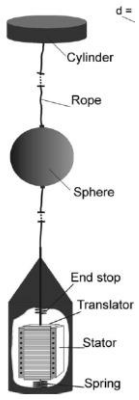
Case Study



parameter	Value	Unit	comment
Number of modules	10		10 identical 3 phase units to make one single module
Average real power output	25	kW	
Rated force	44	kN	Average force over electrical cycle
Overload force	81	kN	Average force over electrical cycle
Amplitude of oscillation	1.375	M	(i.e.2.75m peak to peak)
V_{phase} output	240	V_{rms}	Limit of DC voltage
Current density	3.5	A/mm^2	RMS over full mechanical cycle
	7	A/mm^2	Peak value at peak of rated power
	12	A/mm^2	RMS at overload condition
	17	A/mm^2	Peak value at peak overload power

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General Linear generator development

- Slow speed machines tend to imply permanent magnet topologies
- Good magnetic circuit implies poor power factor
- Balance between VA rating and magnet mass
- Have designed for 2.5kW and 25kW
- Have investigated wide range of topologies
- Now doing laboratory validation and considering device integration.

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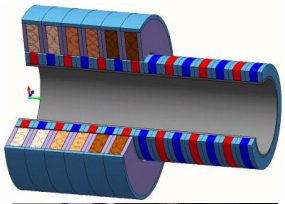
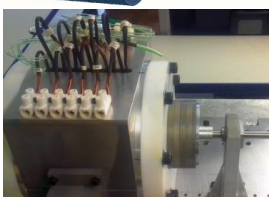
Electrical Machine options

- Topologies
- Pole shape
- Single or double sided
- Flat or linear





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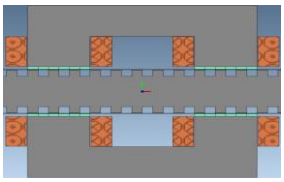

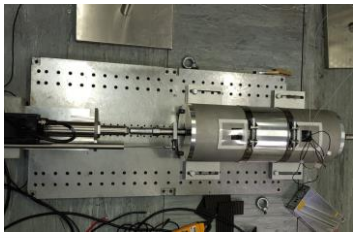

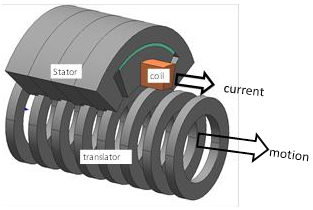

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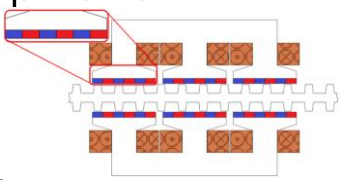

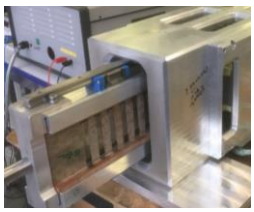

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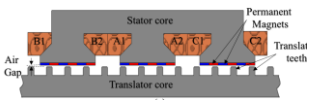

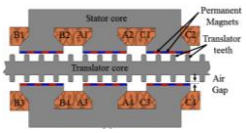

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Electrical Machine options

- Topologies
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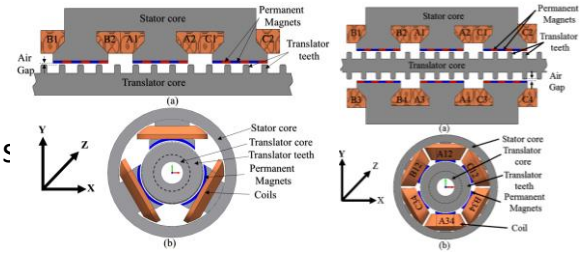

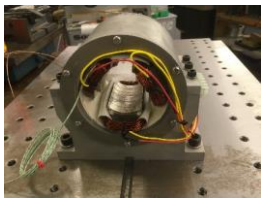

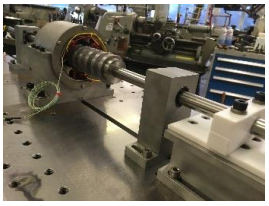

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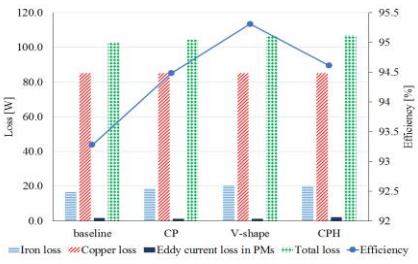
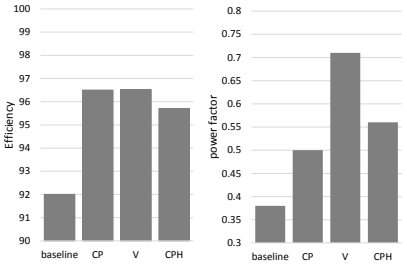
Topology Assessment

$$CoE \approx \frac{A \times magnet\ mass + B \times 1/power\ factor}{\eta}$$



Machine efficiency of all topologies at fixed current density



Efficiency and power factor for all machines with a constant mechanical power achieved by varying current density.

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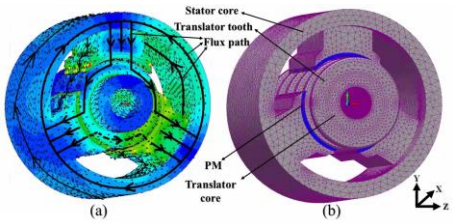
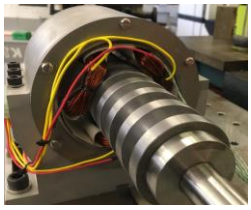
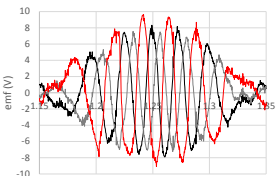
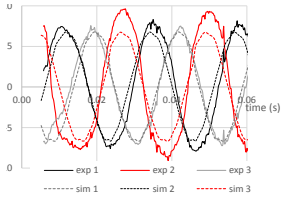
Cylindrical development









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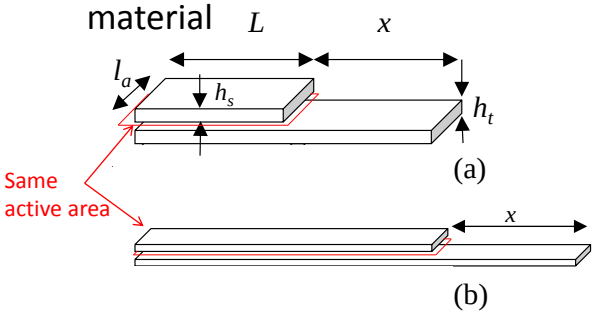
Long verses short

- Aspect ratio is important
- In general, long thin machines use less active material



$$X = \frac{x}{L}$$

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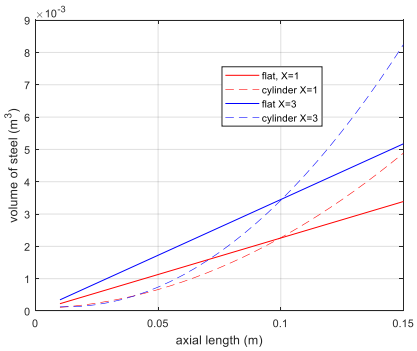
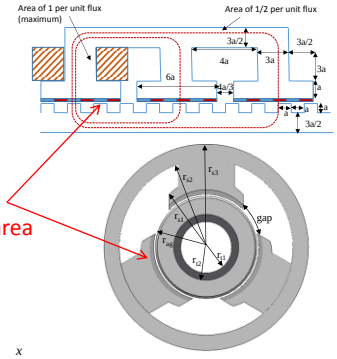
Cylindrical verses flat

- Cylindrical machines lighter at low X



Same active area



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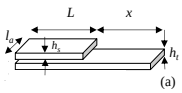

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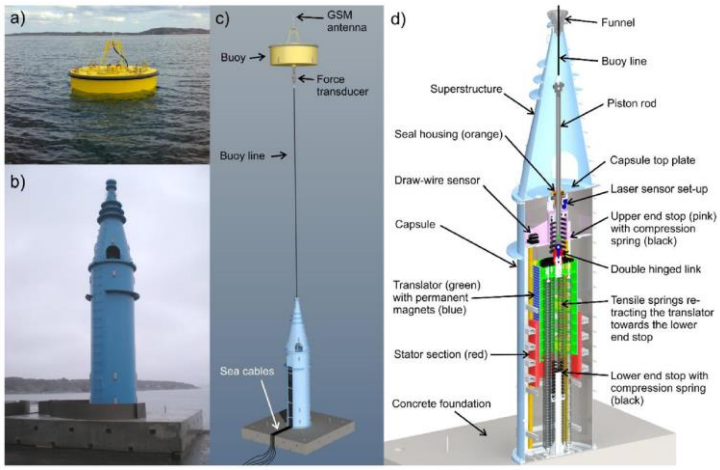
Integration



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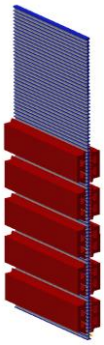

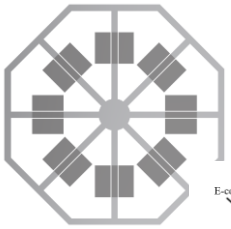

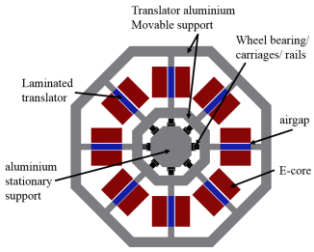

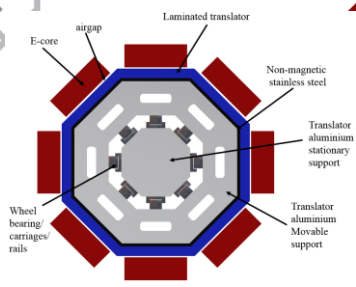

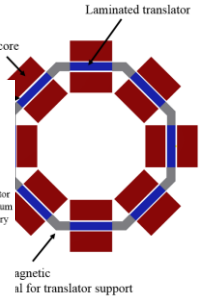

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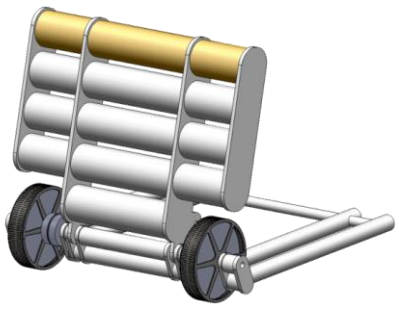
Magnetic gear case study

- Peak force req. 6.2 MN (low speed side)
- Peak Velocity ~ 2rpm
- Split into two PTOs



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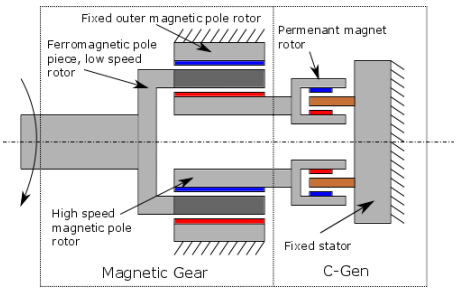
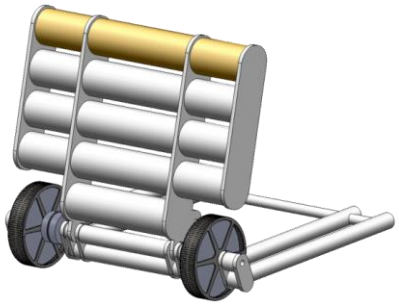
Magnetic gear case study

- Speed/torque ratio: 10.24
- 1.4m radius, 3m axial length





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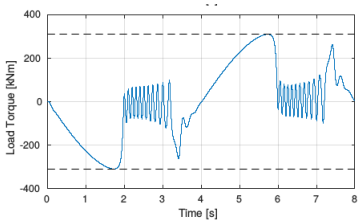
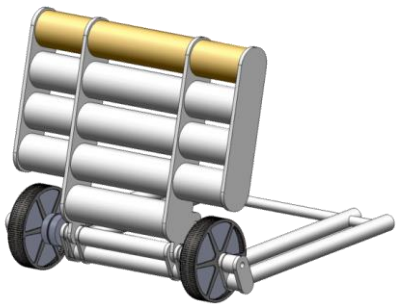
Magnetic gear case study

- Inherent slip / resynchronise characteristic
- Small prototype to be built and tested to explore dynamic performance
- Linear gears also investigated





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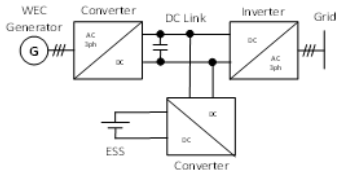
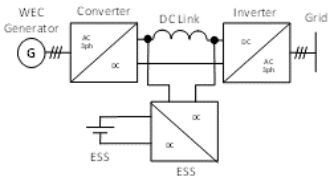
SUPERGEN GRAND CHALLENGES

Power Converter





- Voltage Source
- Conventional
- Energy stored in capacitor
- V DC link fixed

- Current Source
- Energy stored in inductor
- DC link can vary
- Size of inductor reduces with frequency…but losses increase

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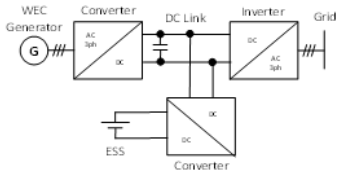
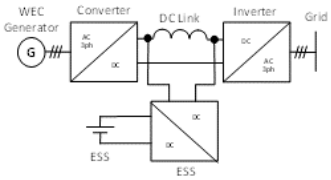
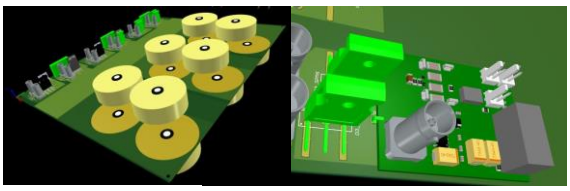
Power Converter





- Voltage Source

- Current Source



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SUPERGEN GRAND CHALLENGES

[end of converters]

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SUPERGEN GRAND CHALLENGES

Next steps

- Finish machines testing (5 machines)
- Commission VSC
- Finish CSC
- Implement control of machine with converter
- Couple machine VS Converter to a scale WEC in a tank work

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Next steps

- Finish machines testing (5 machines)
- Commission VSC
- Finish CSC
- Implement control of machine with converter
- Couple machine VS Converter to a scale WEC in a tank work

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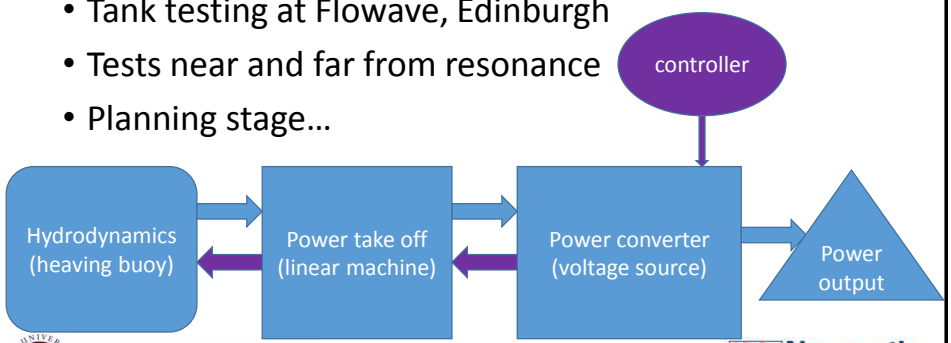
Tank testing

- Aim is to demonstrate all electric control and power off for a WEC
- Tank testing at Flowave, Edinburgh
- Tests near and far from resonance
- Planning stage…



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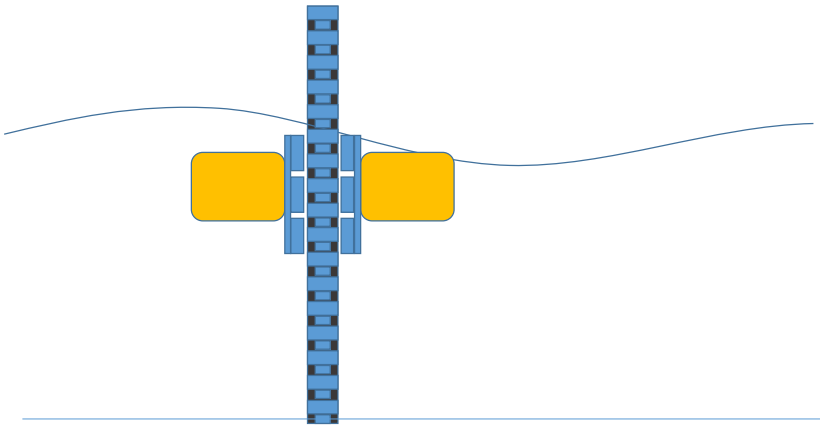
Options for tank testing 1: constrained heave



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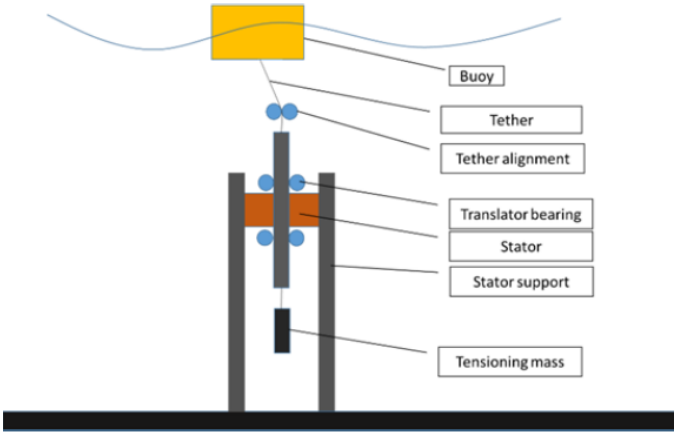
Options for tank testing 2: Tethered



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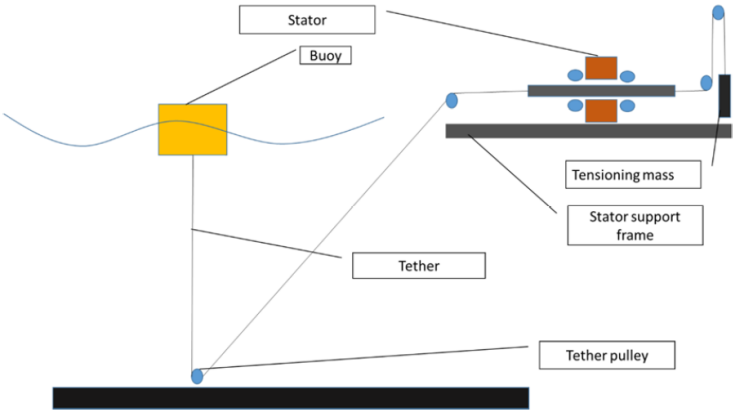
Options for tank testing 3: string power take off



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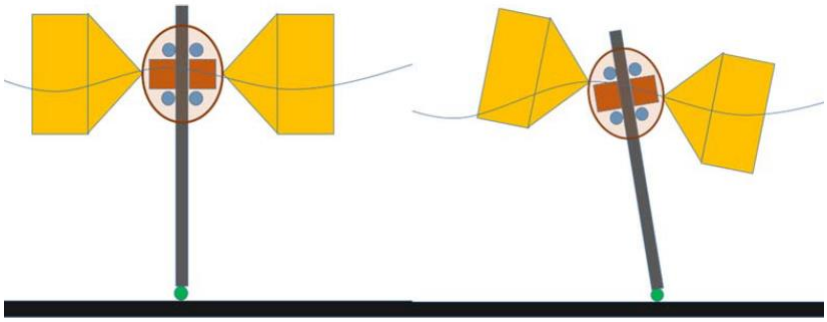
Options for tank testing 4: free floating integrated



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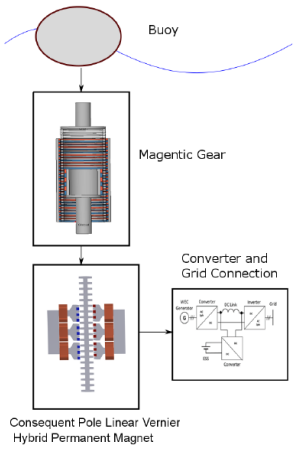
Agenda 2018

- Welcome & Introductions (Simon)
- Work-package updates
  - Electromechanical Development, Magnetic Gearing Systems, Power Converters and Control (Nick)
  - **Wave to Wire Modelling (Richard)**
  - Technology Roadmap (Simon)
- Future development discussion (All)

Linear PTO system

Collaborating with Newcastle University, a linear combined system was proposed and analysed for efficiency, reduced mass and material costs.

The full study has been accepted for presentation at IET Renewable Power Generation 2018 Conference in Denmark



Prototype Development

2 prototype gears have been designed and developed with Fountain Design. Each gear with a pull out torque of 40-50Nm and ratio 7.33:1. With the first built testing will soon begin to establish efficiency and dynamic effects.

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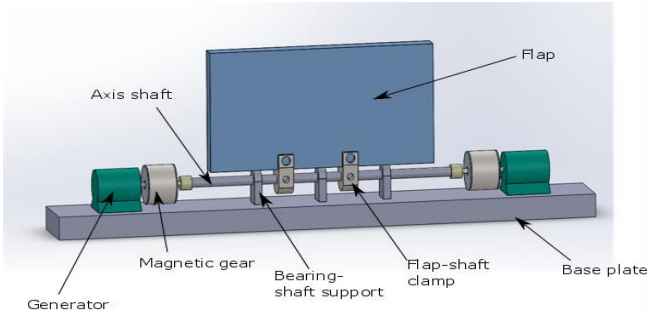
Gear System Testing

Upon completion the gears will be combined with generators and tested as a PTO for an oscillating wave surge converter, "Flap" device. Testing will take place at Flowave in August.



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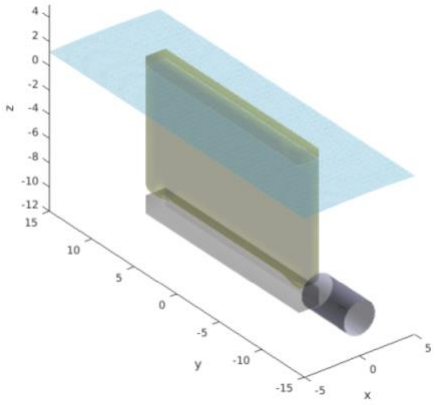
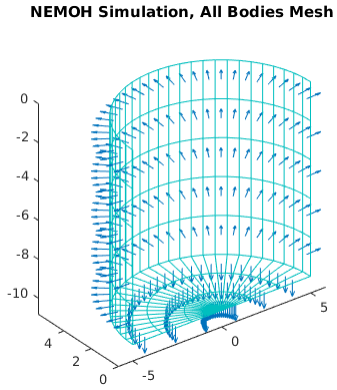
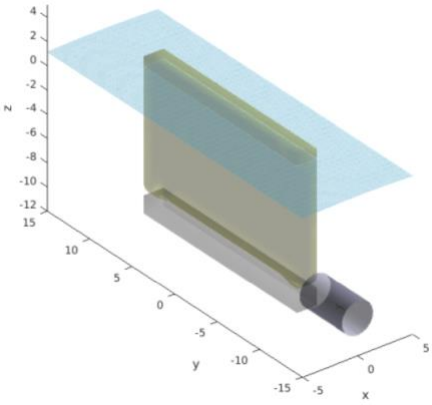
Wave-to-Wire Modelling

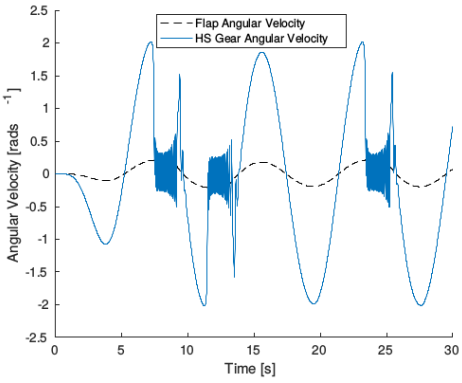
Created first release, version 1.0 of the wave-to-wire model





Wave-to-Wire Modelling





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Next Steps

- Expanding on the developed design tools capabilities, axial, Halbach array and flux focusing type gears are being investigated for lighter and cheaper gears with greater torque densities.
- Staged systems are also being investigated to allow for ratios exceeding 100:1
- Case studies of partner's systems

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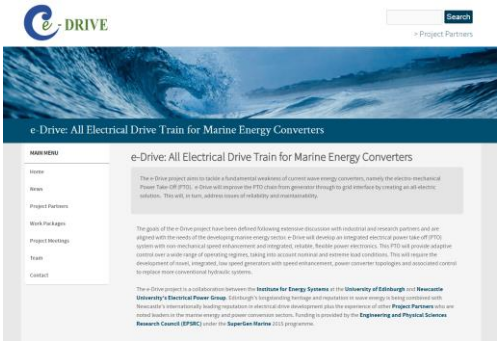
Work Package 7 – Industrial Engagement and Impact Management

- Industrial Advisory Board
- Commercialisation Roadmap
- Impact enhancement and monitoring
- Project website and newsletter



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Commercialisation Roadmap

- Due in month 30
- Identify priority challenges in the marine energy sector
- Highlight where e-Drive helps overcome these challenges
- Identify barriers to e-Drive uptake (e.g. policy, regulation and legislation)
- Develop methods moving past these barriers
- Ensure that e-Drive outputs are deployed and accepted in the market beyond the end of the project

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Future development discussion (All)

Discussion points and questions

- Industry needs
- Project opportunities
- Funding opportunities
- Development strategy
- Next steps
- Conclusions

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