Tension Technology International

Elastomers in Energy Transition

The Application of Dielectric Elastomer Generation in Wave Energy Convertors

Tom Mackay CEng FIMechE

London, 28th March Feb 2025

wave energy SCOTLAND

I·M3 Institute of Materials, Minerals & Mining

Elastomer Group

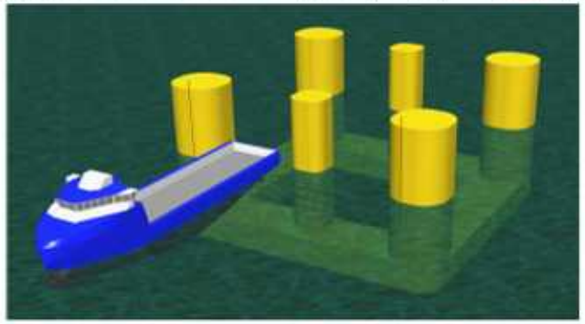
I·M3

STRUCTURE

- Introductions
- What is wave energy? What is a Wave Energy Convertor?
- A step back – elastomeric hulls. Why elastomers?
- Why dielectric generators?
- What is an Electroactive Polymer / Dielectric Elastomer Generator?
- Preliminary concept engineering investigations
- Challenges
- Addressing the challenges
- Shaping the research agenda
- What next?

Tension Technology International

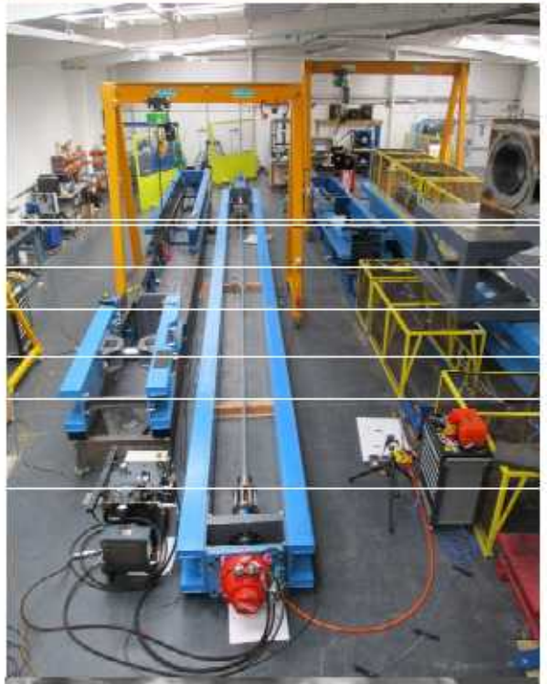
TTI Ltd (Eastbourne)	O&G and marine

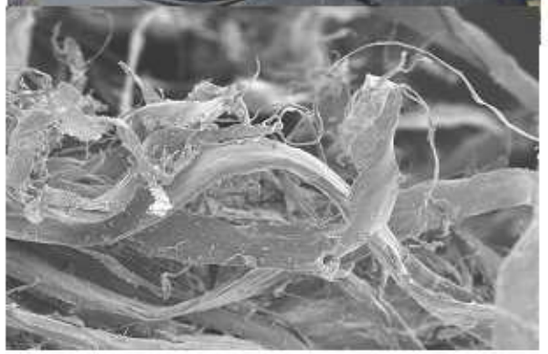


TTI is an independent research, design and development company; est. 1986.

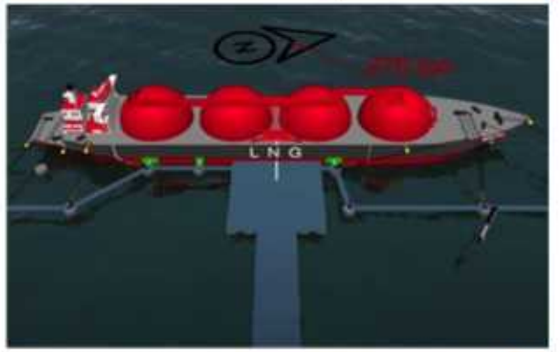
TTI Marine Renewables Ltd (Inverness)	Renewables focus

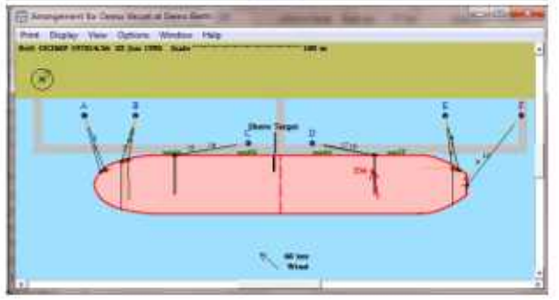
TTI Testing Ltd (Wallingford)	Rope, chain & cable testing services





Optimoor™	Licenced mooring software



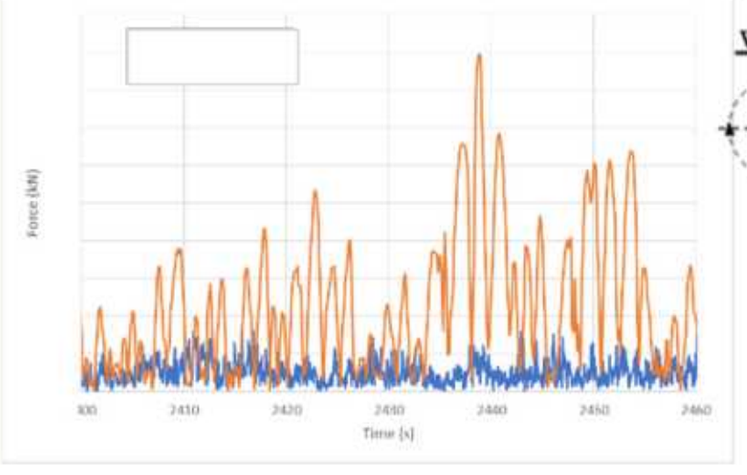


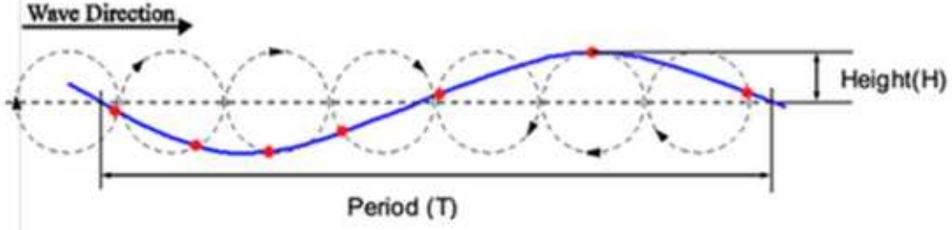
Services include design, engineering and testing of fibre rope, wire, chain, cables, fabrics, mooring systems, riser protection nets and subsea tethers.

WHAT IS WAVE ENERGY?

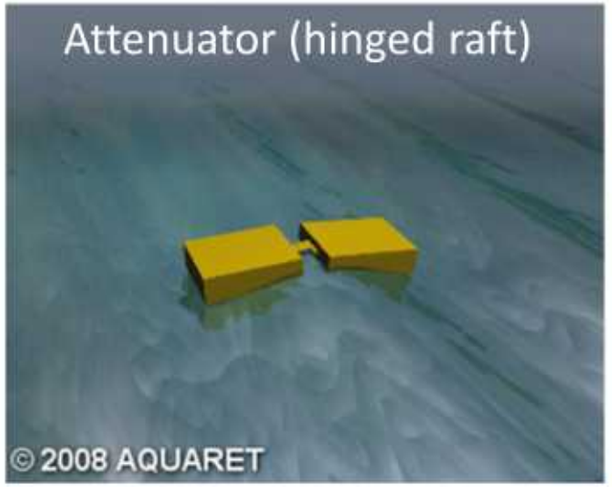
- Wave energy is the world's largest untapped source of renewable energy
- Ocean waves are gravity waves generated on open water by wind (concentrated solar)
- The waves efficiently store and transport kinetic energy (not water!)
  - High energy density for renewable sources
- Wave Energy Convertors (WECs) interact with the waves to do useful work e.g., electricity generation
- Wave power is proportional to wave height squared and wave period
  - "Normal" seas might be 30 kW/m but need to survive storms at >1 MW/m – big challenge

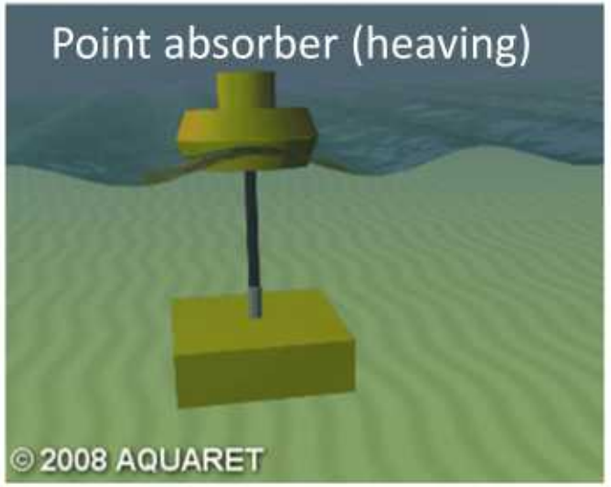
https://corpowerocean.com/wave-energy/

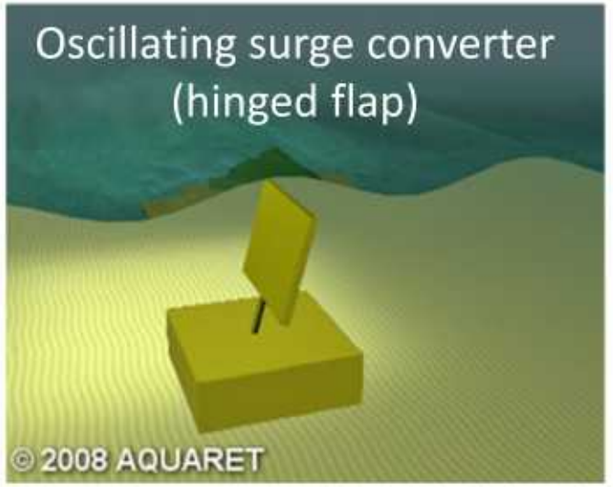


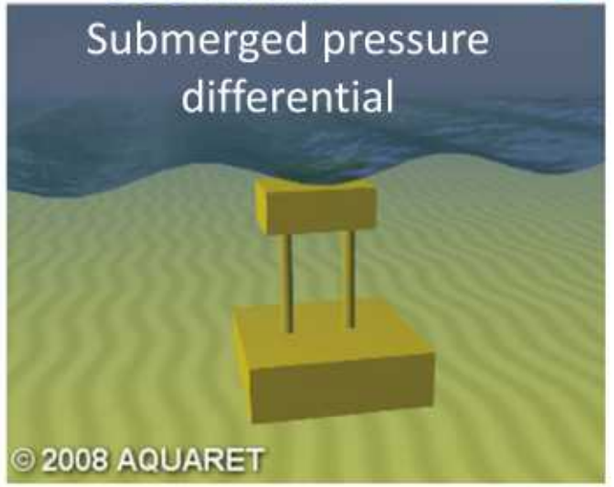


WAVE ENERGY CONVERTOR TYPOLOGIES

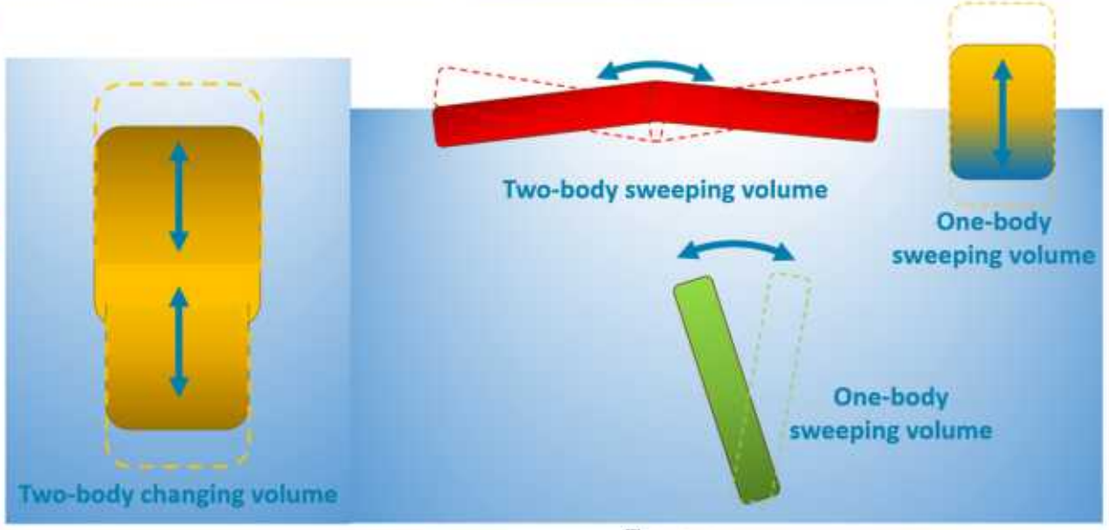


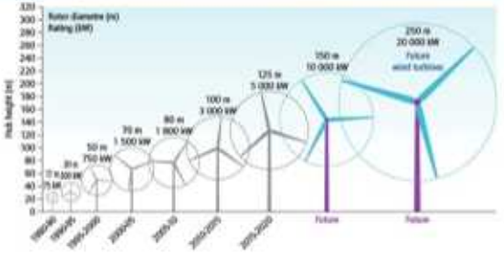






- Common WECs have a volume displacing hull that "sweeps" through a volume as it moves due to wave forces – the wave absorption mechanism
- The motion (v) is damped (F) with reference to another rigid body or the seabed by the power take off (PTO): P = F x v
- The PTO system (and motion) is typically linear or rotary
  - Linear generators, gearboxes and rotary generators, hydraulic systems (linear and rotary), air turbines
- These typologies mandate large rigid hulls and complex PTO systems
  - Weight, cost, complexity, corrosion, maintenance challenges = Cost of energy challenges





A STEP BACK – REINFORCED ELASTOMER HULLS – NetBuoy™

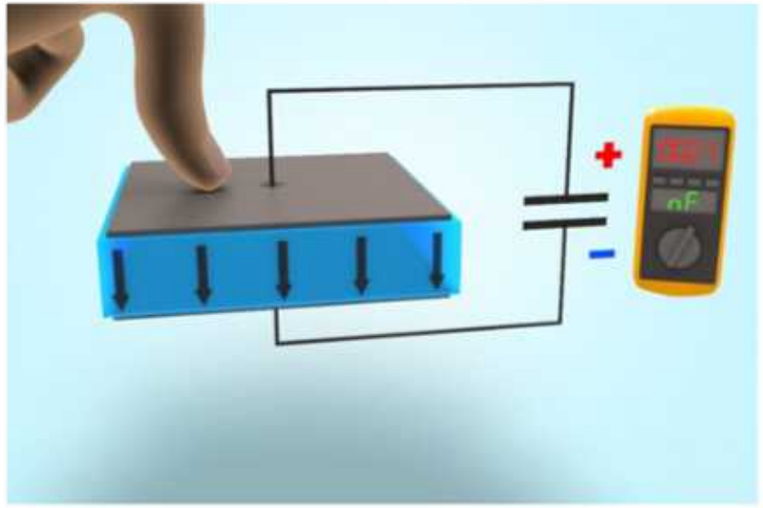
- Elastic response in peak load events – inherently peak-load shedding
- Light weight
- More cost effective than steel hull
- Well suited to mass manufacture
- Applicable to range of WEC types
- No corrosion
- Fold it up and put in a box for transport
- Installation advantages
- Now being integrated with full WEC with American developer Anacapa Wave Power

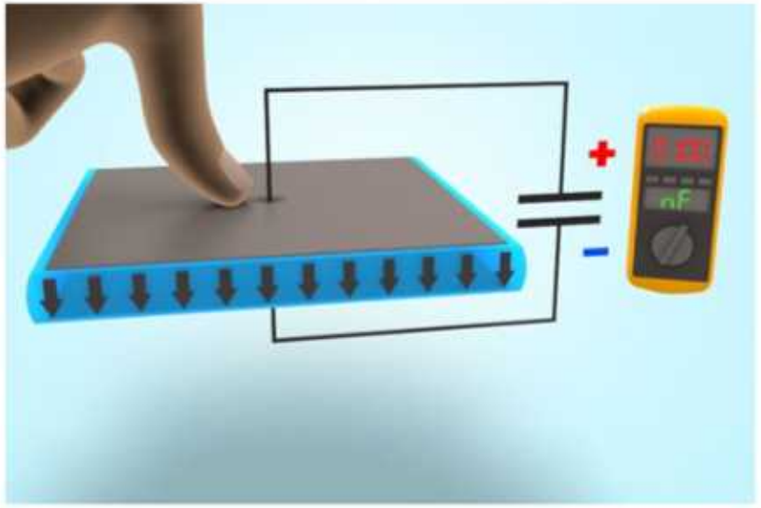
RADICAL INNOVATION

- What if the benefits of a passive reinforced elastomer hull are conferred into the power take off system as well?
- What if the power take off system becomes more distributed and integrated into the overall hull structure?
- A new class of WEC that directly converts the mechanical energy to electrical energy
  - Compliant inherently load-shedding structures
  - Delete complex, heavy, costly sub-systems
  - Improve percentage of WEC mass involved in energy conversion
  - Highly modularized and suited to mass manufacturing methods
  - Cost of energy improvements

ELECTROACTIVE POLYMER INTRODUCTION

- A sandwich of dielectric and conductive elastomers
- This forms a variable capacitor – the capacitance varies with applied strain
- Applying a voltage causes mechanical movement/force: actuator
- Applying a force causes strain that changes capacitance that can be measured: sensor
- Applying a force/motion and electrical charge produces a net gain in electrical energy
  - Mechanical work (strain energy) transforms to electrical energy
  - The metamaterial becomes an electrical generator
  - The most challenging application for EAP



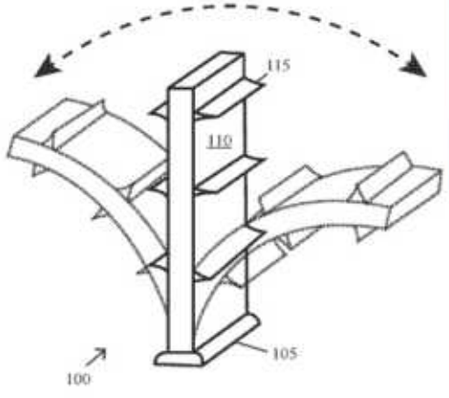


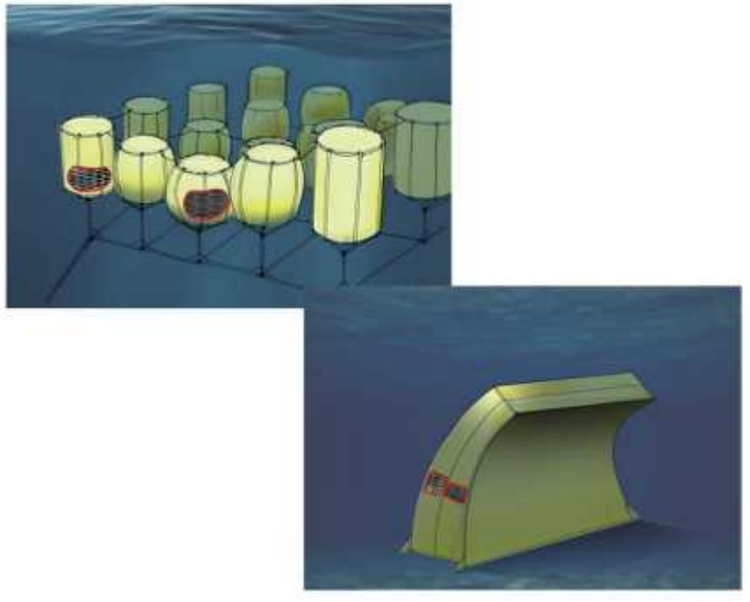
https://www.wacker.com/cms/en-us/products/applications/electrics/electroactive-polymers/electroactive-polymers.html

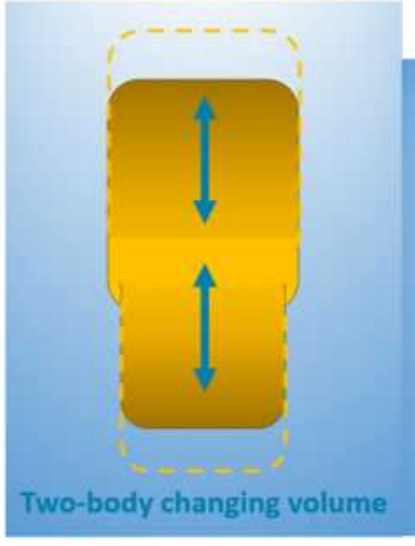
WACKER

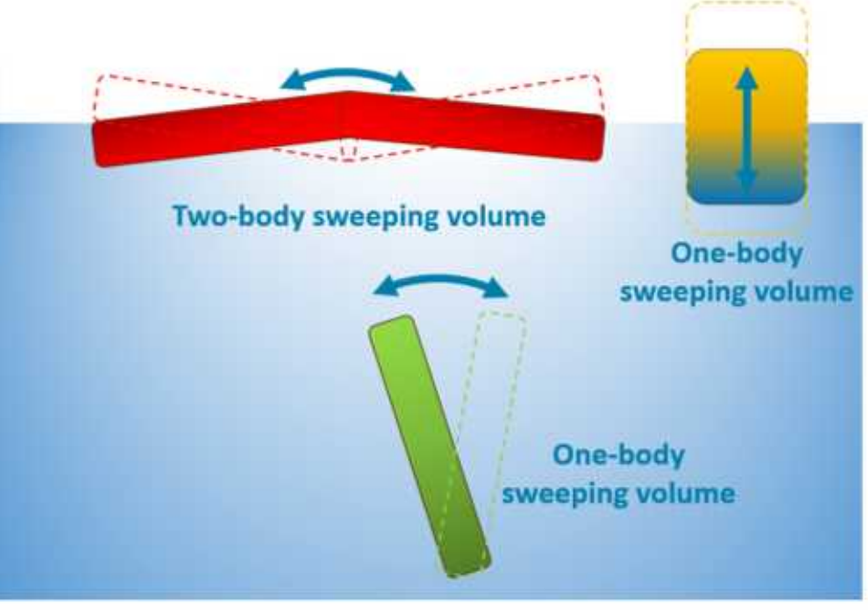
WHERE TO START? REQUIREMENTS DEFINITION

- A deep dive on the requirements for effective wave energy capture and the DEG material characteristics
- First thoughts about coupling material characteristics with wave energy absorption fundamentals
  - What does an ideal WEC look like?
  - How do we best make use of the proposed benefits of DEG?
- What has been done to date in the field – global IP and research papers

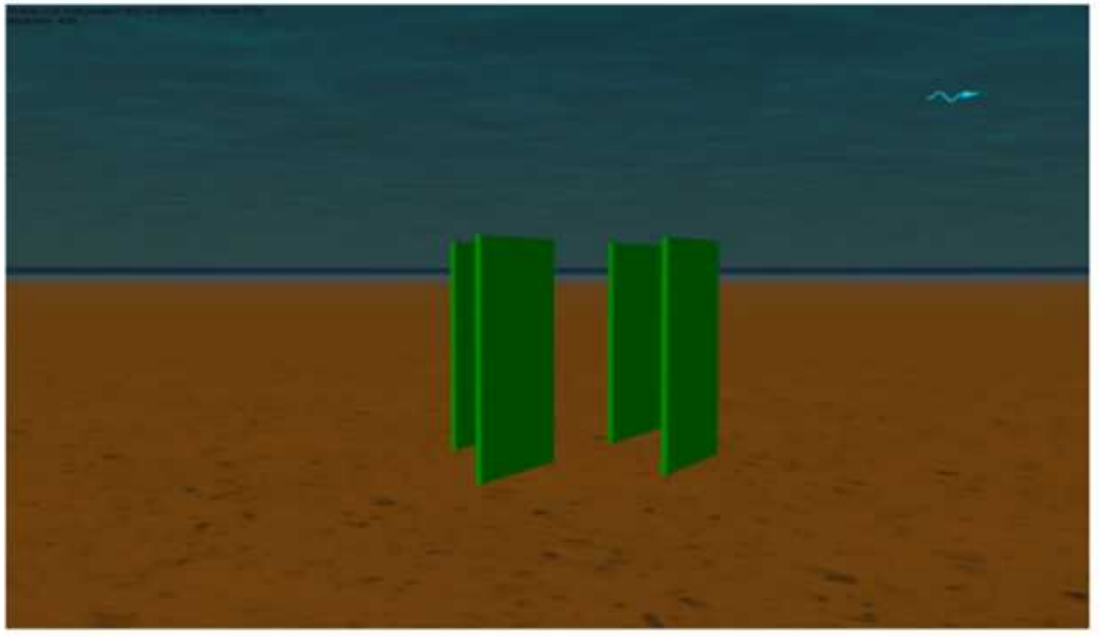


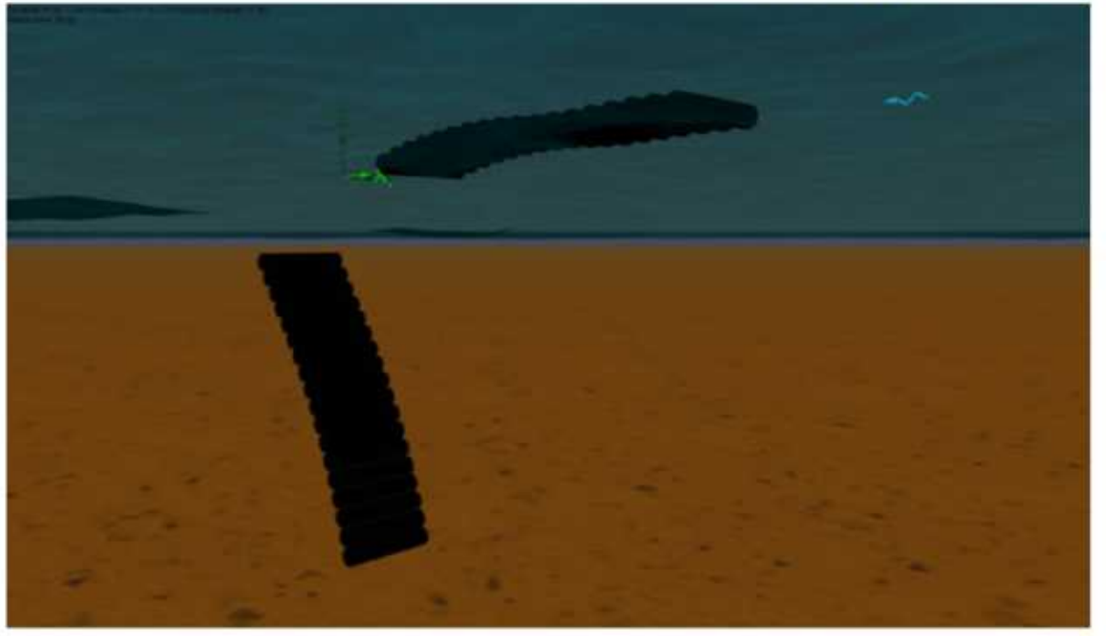






CONCEPT DEVELOPMENT AND ASSESSMENT





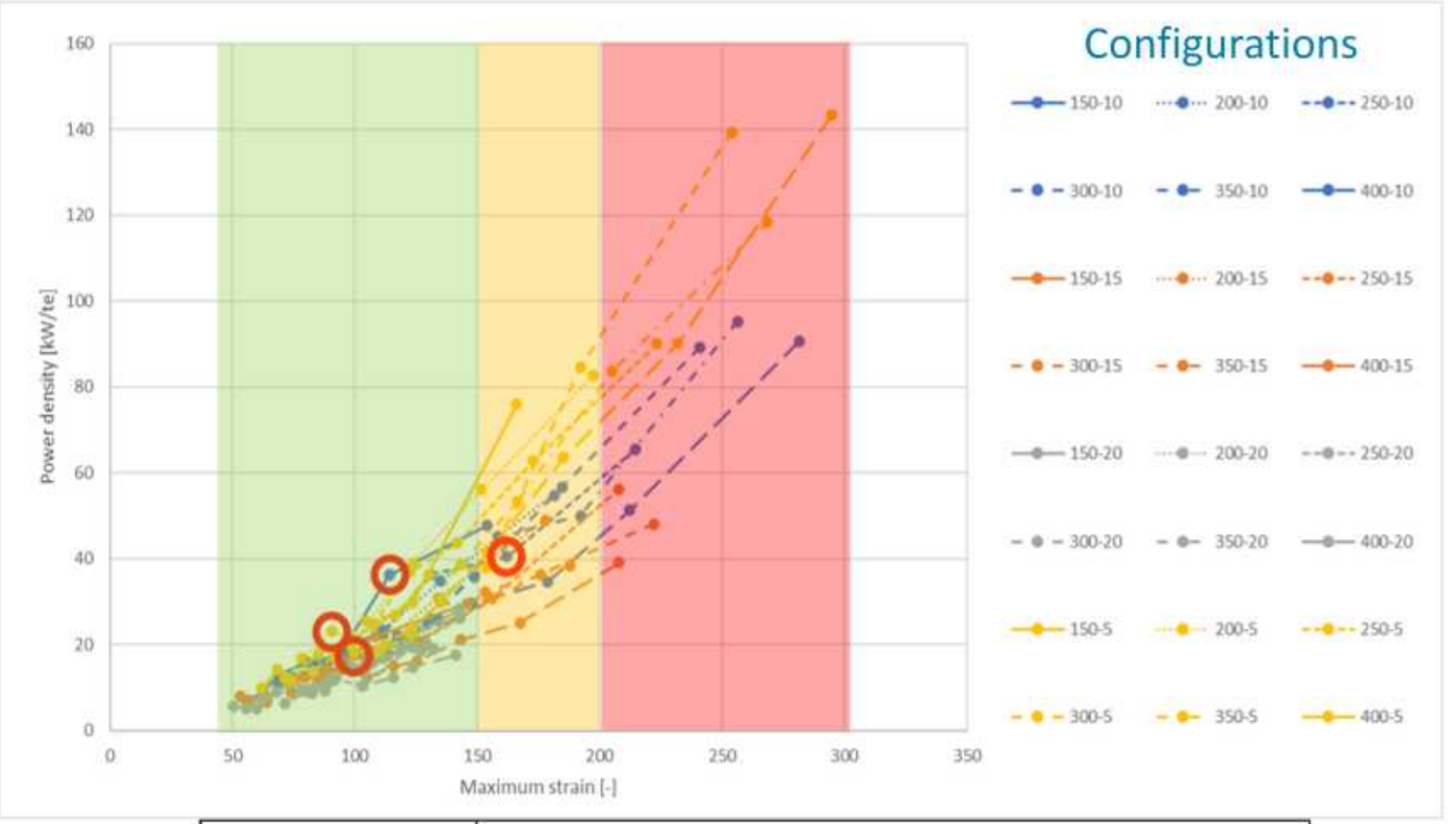
- Developing appropriate methods to assess flexible structure concepts
- Use of modelling tools to promote the creative process
- High-level comparisons between device motions
- Good for fixed-volume-swept-volume
- Useful to observe strain ranges for given wave input and typical motions
- Preliminary parametric studies

REQUIREMENTS TECHNICAL ASSESSMENT

- A suite of design tenets and requirements
  - Describing the design vectors at an ideal and pragmatic level, with justification
- Maximise volume of DEG material actively utilised in the device
- Minimise volume of material in device that is **not** DEG
- Minimise strain discontinuities
- Achieve high DEG strain range
- Focus operating range in “soft” part of elastomer stress-strain curve
- Utilise DEG loading (strain) mode that drives large generation factor
- Develop a design concept that is scalable
- Be hydrodynamically well-coupled in operating waves
- Be survivable
- Be novel

TECHNO-ECONOMIC ASSESSMENT: £/kWh

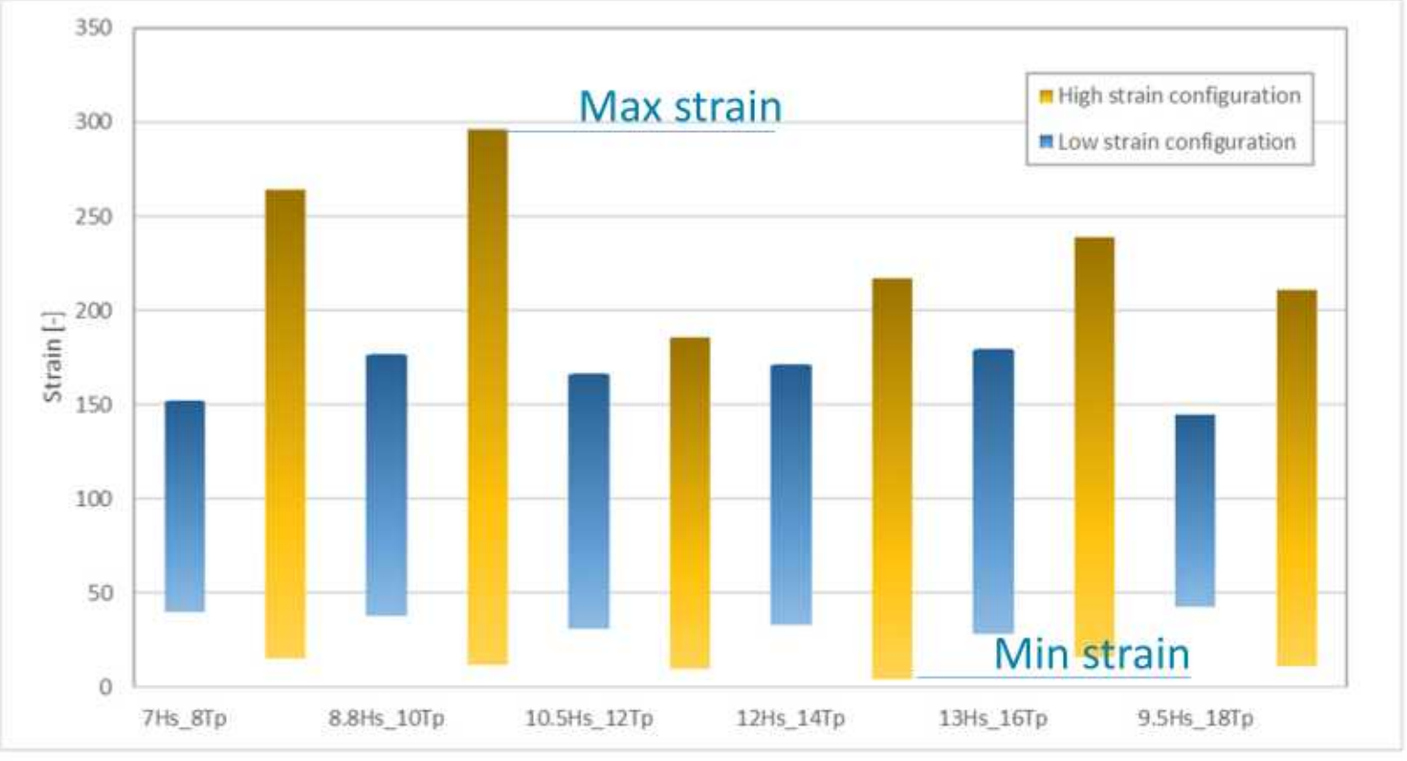
- Challenging:
  - How to compute performance with reasonable accuracy and certainty?
  - How to compute system costs?
- Parametric global optimisation over number configurations
  - Maximise operating strain range
  - Minimise zero strain events
  - Avoid high peak strains in energetic waves
  - Maximise wave energy absorption / mechanical work
  - Design trade-off between power density and operating strain range
- **What is the fatigue response of the EAP???**
- **Where is it "safe" to operate?**

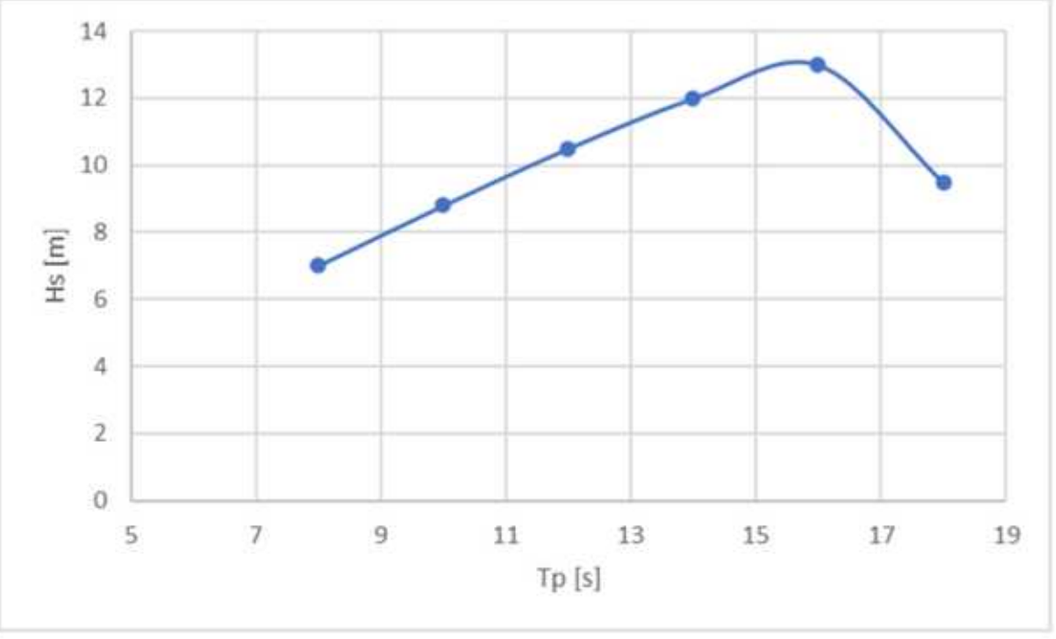


Normalised average damper power		Tz [s]										
		4	5	6	7	8	9	10	11	12	13	14
Hs [m]	1	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
	2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
	3	-	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2
	4	-	-	0.9	0.7	0.6	0.5	0.5	0.4	0.4	0.4	0.3
	5	-	-	-	1.0	0.8	0.7	0.6	0.6	0.5	0.5	0.4
	6	-	-	-	-	1.0	0.8	0.7	0.7	0.6	0.6	0.5

SURVIVABILITY

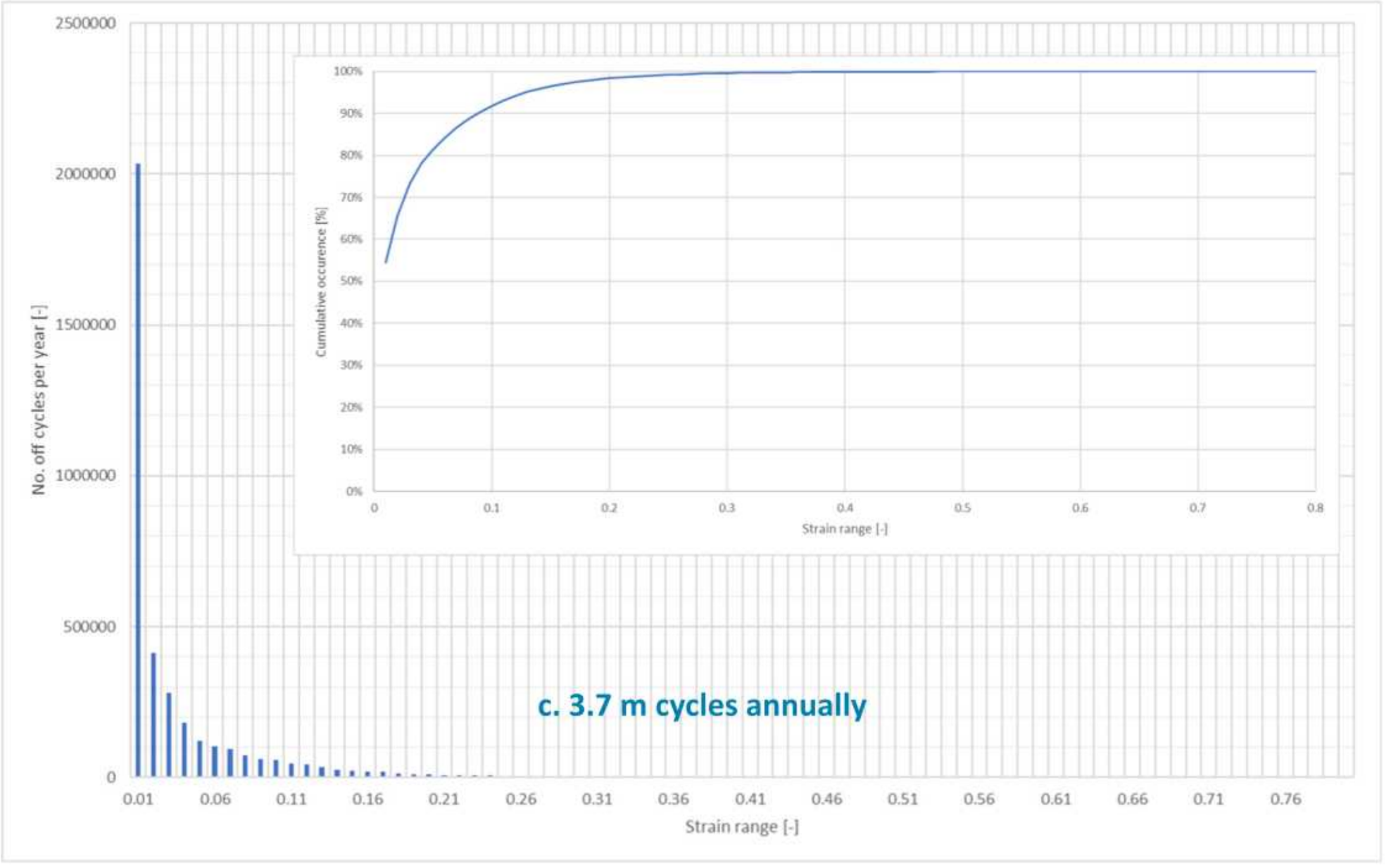
- Six exposed 1 in 50-year return survival seastates selected representing NW Scotland Atlantic or NW Norway North Sea
- Tested for four preferred configurations
- Operating waves drive fatigue; survival waves drive ultimate limit state





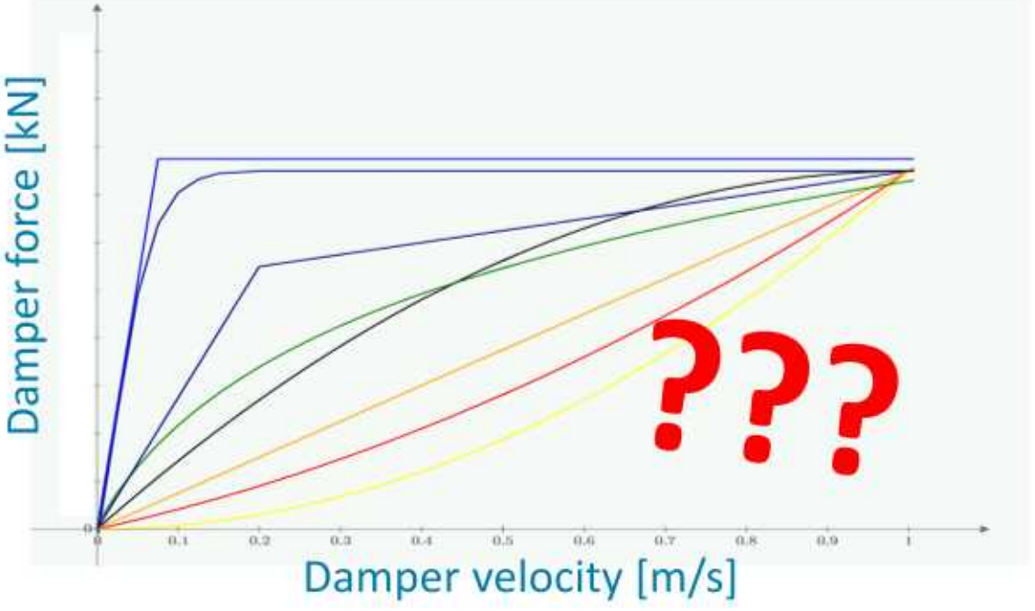
FATIGUE SPECTRA

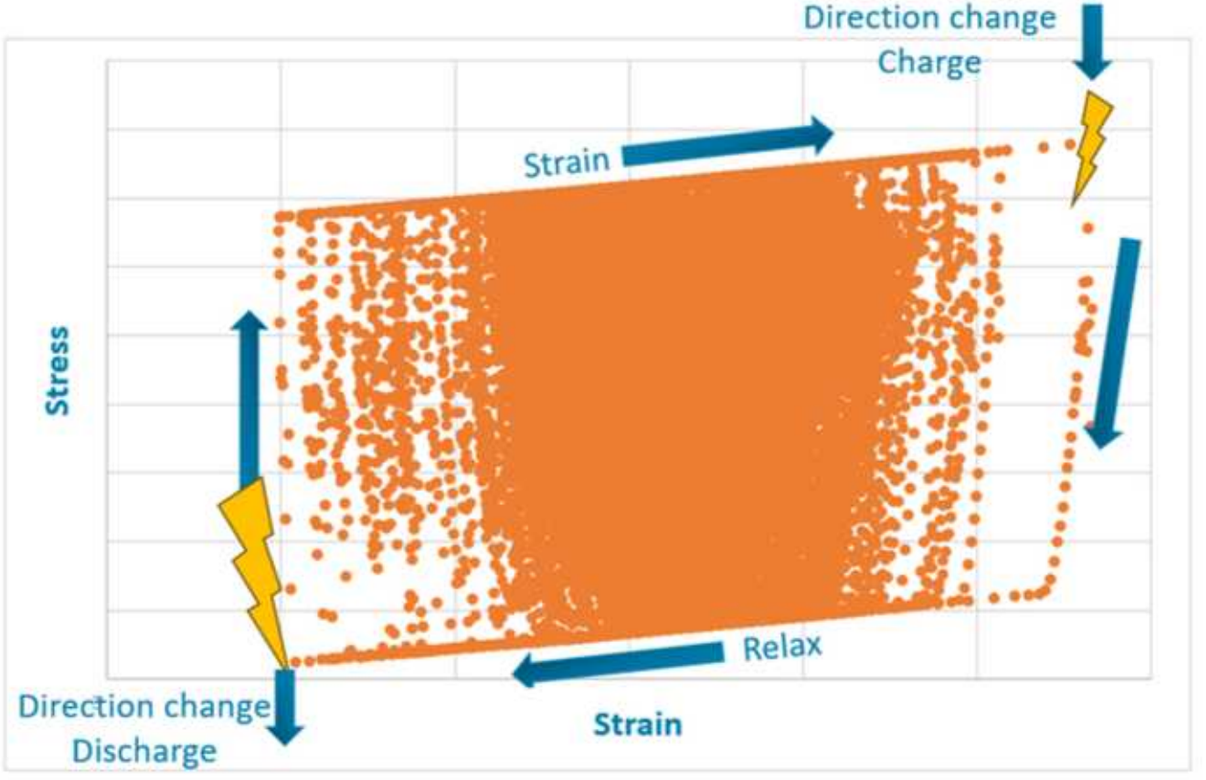
- Large strains occur but 98% occurrence less than c. 0.2 strain range
- Is this okay?
- Or not okay?
- Paucity of published data to assess



ACTIVE DAMPING

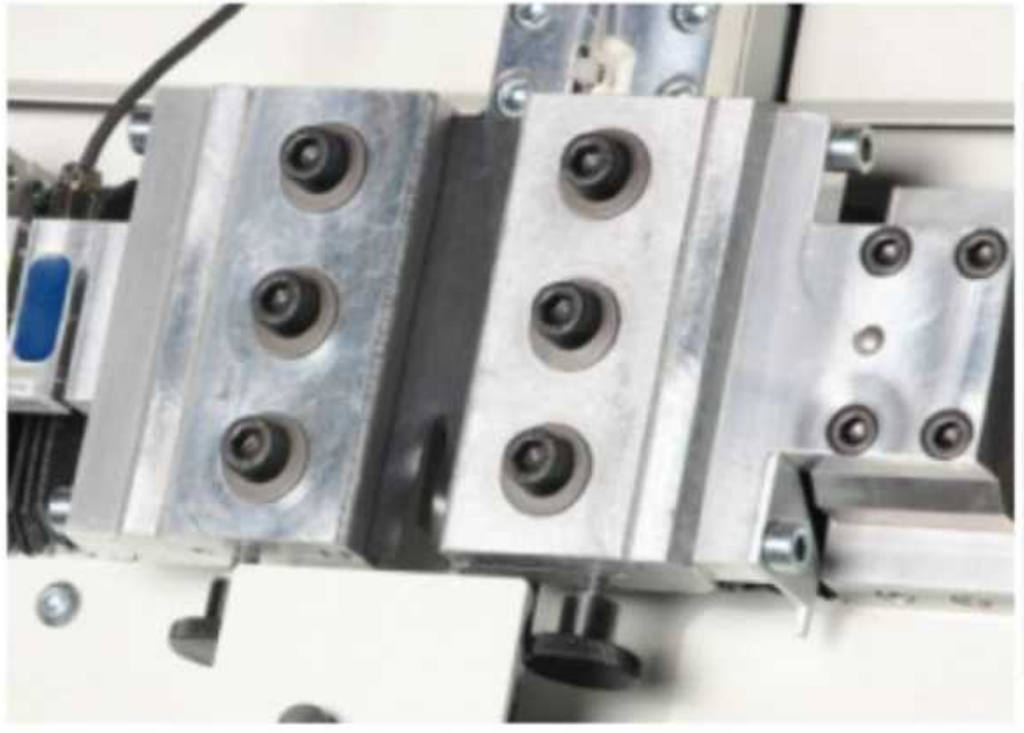
- The DEG converts mechanical work to electrical energy
- A flow of energy out of the system
- Manifests as a loop in load-elongation curve with enclosed area being the useful work done
- **How big can the loop be???**
- **What is the damping force characteristic???**



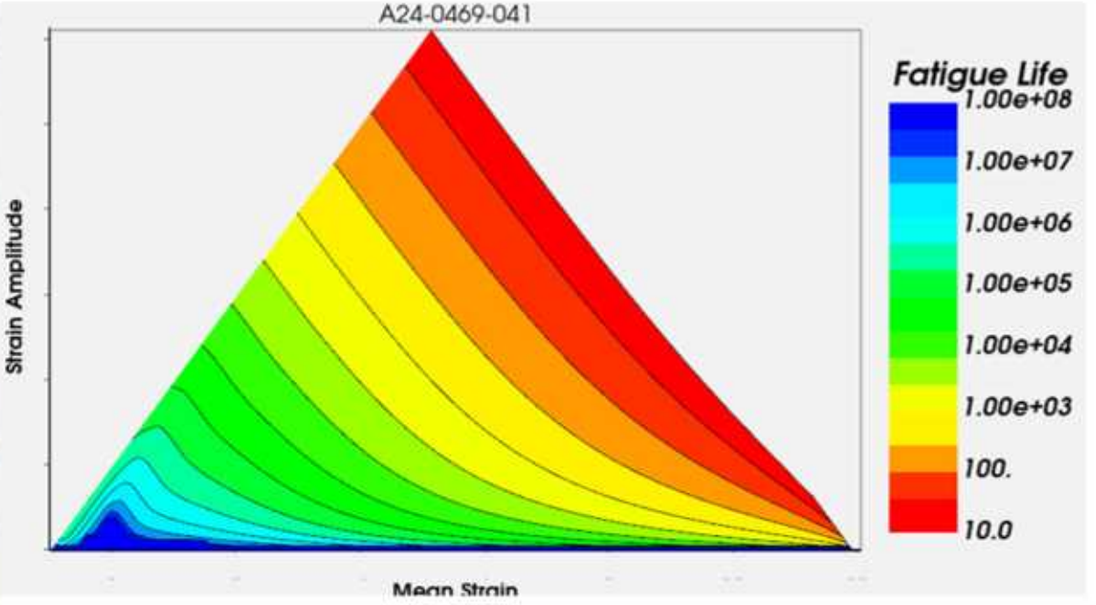


BEGINNING TO ANSWER THE BIG QUESTIONS

- Key challenges to investigate:
  - Characterise fatigue, aging and combined electro-mechanical fatigue
  - Microplastic loss rate
  - Conversion performance and improvement – what damping is achievable?



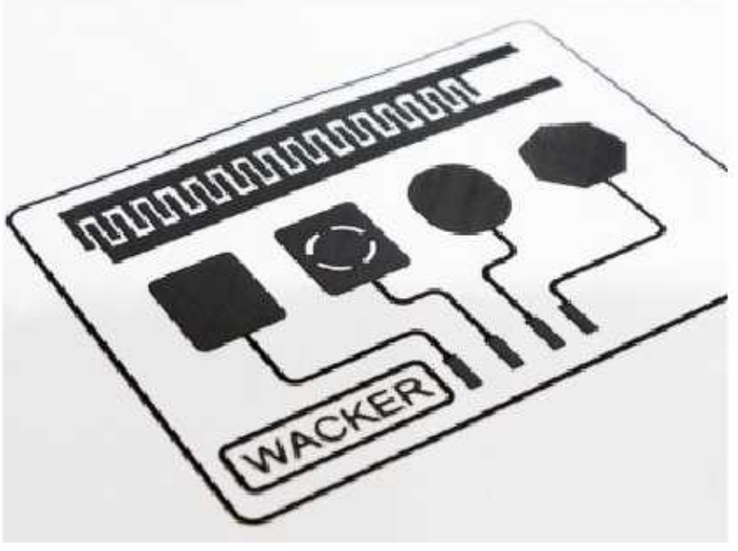
Intrinsic strength testing



Haigh diagram

BEGINNING TO ANSWER THE BIG QUESTIONS

- Manufacturability and system integration
  - Scalability
  - Costs
  - Mechanical and electrical terminations



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https://www.wacker.com/cms/en-us/products/applications/electrics/electroactive-polymers/electroactive-polymers.html

https://www.wacker.com/cms/en-us/products/brands/nexipal/nexipal.html

NEXT STEPS

- Is there enough justification to recommend further R&D investment?
  - This project phase concludes in two months
- Verify global model with tanks tests at appropriate moment
  - Is there a level of appropriate testing that can be performed without *active* DEG PTO??
  - Study hydrodynamics and mechanical energy conversion
- Active DEG model in the tank to verify and step up Technology Readiness ladder
- In-depth material characterisation
  - Electro-mechanical forces
  - Electro-mechanical fatigue
- Pragmatic integrated system design

CLOSING REMARKS

- A fast-paced, fascinating, challenging project
- Clear at this stage that material development is key next step – we need extensive characterisation and specific development for EAP generators
- If the material can be proven to work over the spectra of load cases and other challenges addressed there are compelling benefits for WECs
- Investigate early market opportunities in sensing and actuation to bolster R&D
- Thanks:
  - For listening
  - To the IoM3 for this opportunity to present
  - David and Gail at Rubber Heart, ACE Laboratories, Endurica and Wacker
  - All my colleagues within TTI group
  - And, of course, WES for being a visionary, encouraging and supportive client

www.tensiontech.com mackay@tensiontech.com https://www.linkedin.com/in/tomackay/