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SUPERGEN GRAND CHALLENGES

All electric drive train for wave energy power take off

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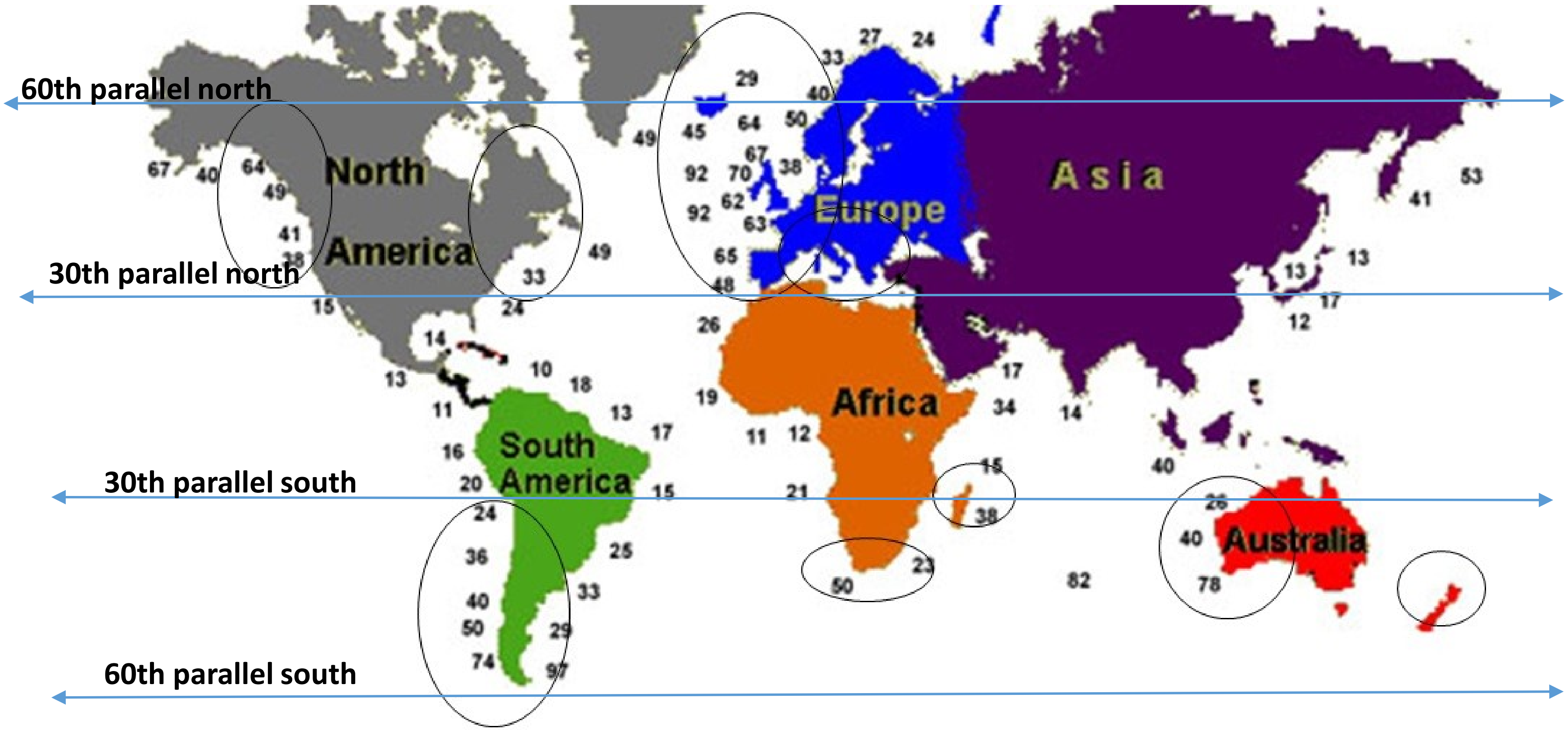
Approximate wave power level given in KW/m of wave front



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Contents

- Power take off in wave energy
- All electric power take off and the E-drive project
- Case studies
- Conclusion

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Contents

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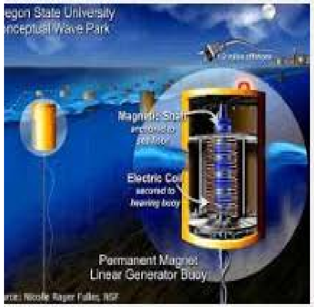
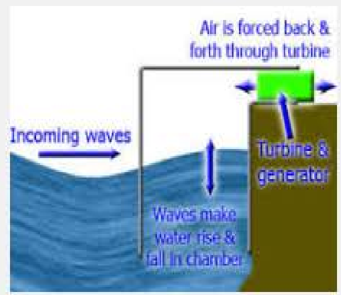
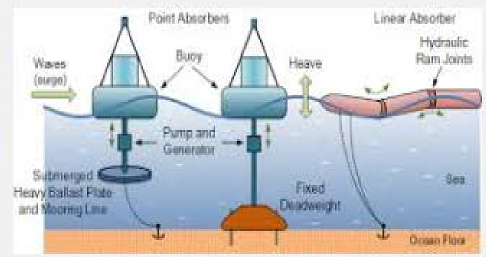
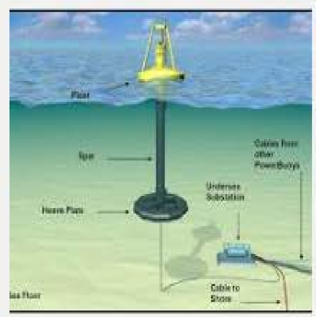
Power take off in wave energy









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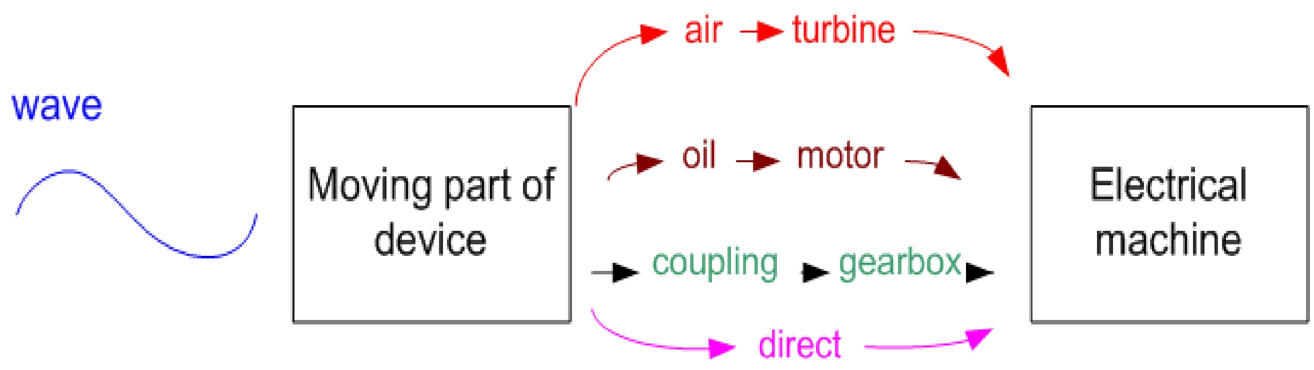
Power take off in wave energy



- PTO and power conditioning system (Conversion of energy from wave into electricity)
  - convert motion in multiple directions
  - React large forces whilst operating at low velocity, variable voltage and frequency
  - High reliability, availability and efficiency over a wide range of loads
  - Life Time Cost of Energy and hence economic feasibility of devices

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All electric power take off and the E-drive project

- **The main aim of the E-drive project:**
  - Developing integrated electrical PTO system with non-mechanical speed enhancement, integrated and reliable flexible power electronics with adaptive control over a range of operating regimes in nominal and extreme load conditions.
  - Development of novel integrated low speed generators with speed enhancement and power converter topologies with associated control to replace hydraulic systems.
- **Challenges:**
  - Slow speeds are a challenge to direct drive
  - Can we have pure electric power take off
  - Do we need internal or external magnetic gearing
  - Does speeding up the capture element give us machine savings?

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Contents

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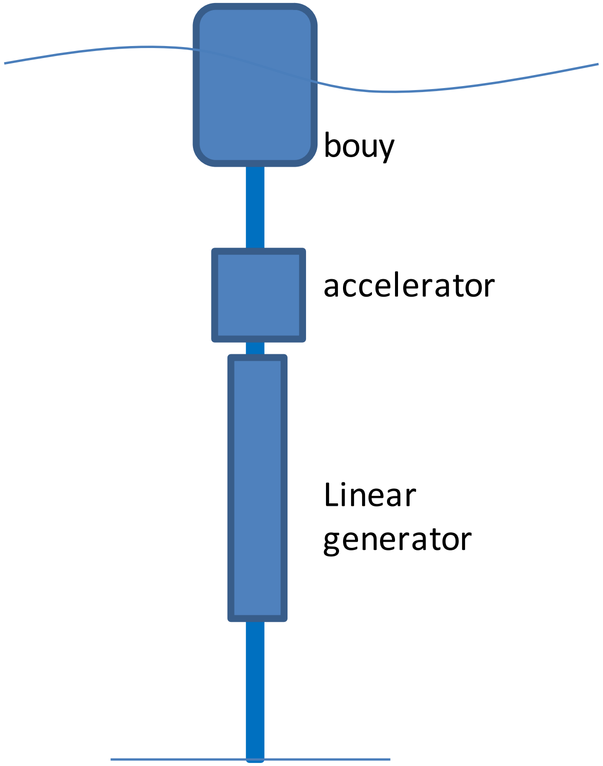
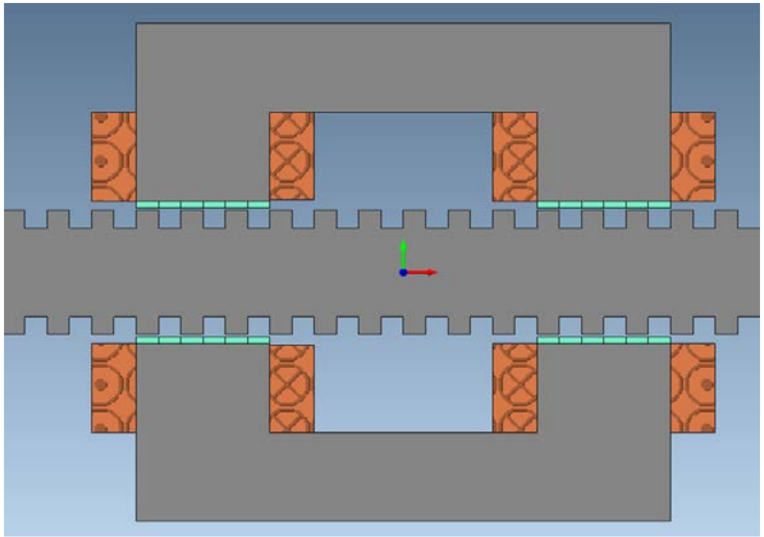
Case Study 1. Heaving buoy with magic box

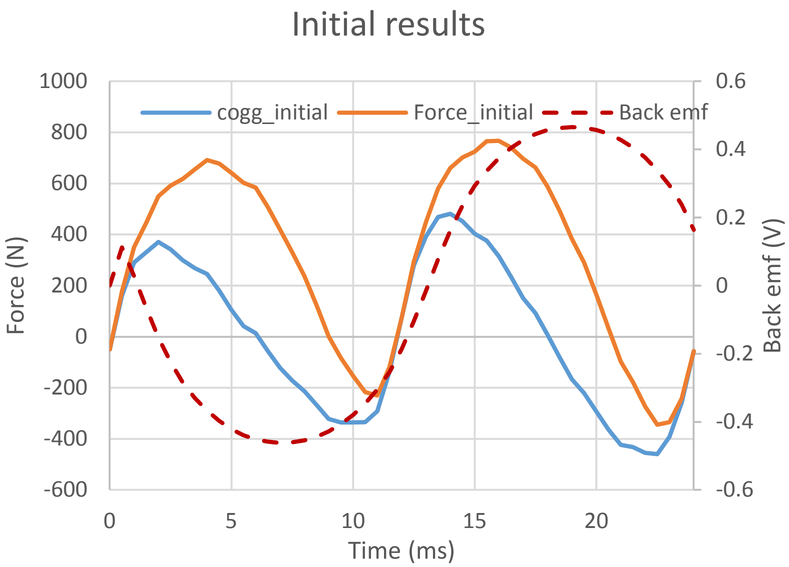


Electrical machine design work

Initial design

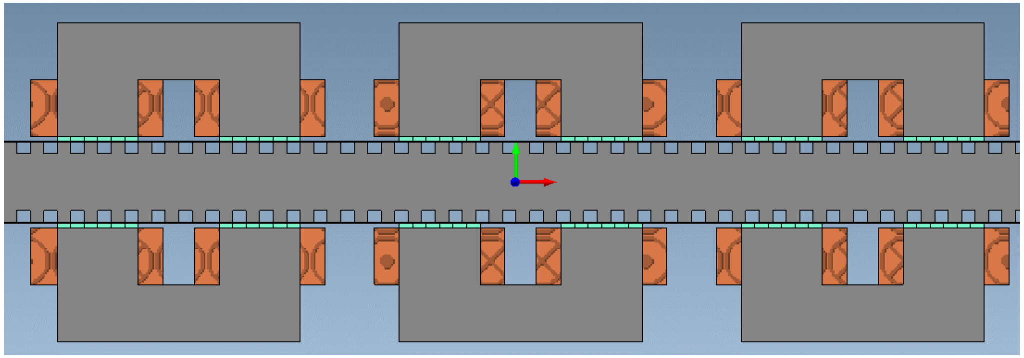
A magnetically geared machine (VHM):

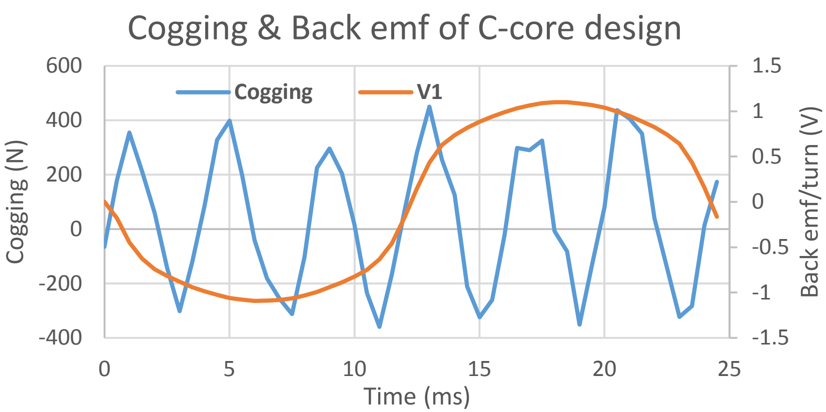


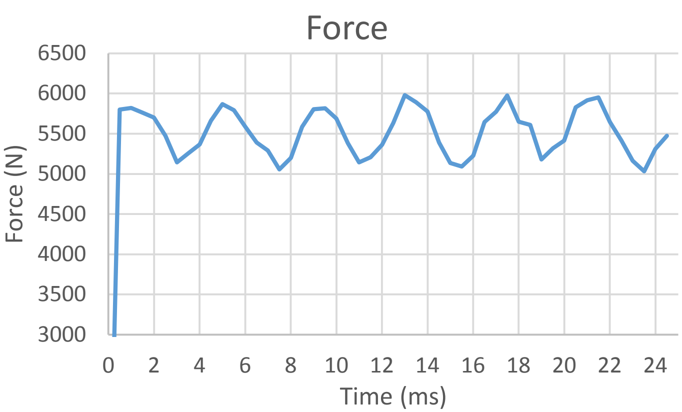


Electrical machine design work

3-Phase C-core Design:







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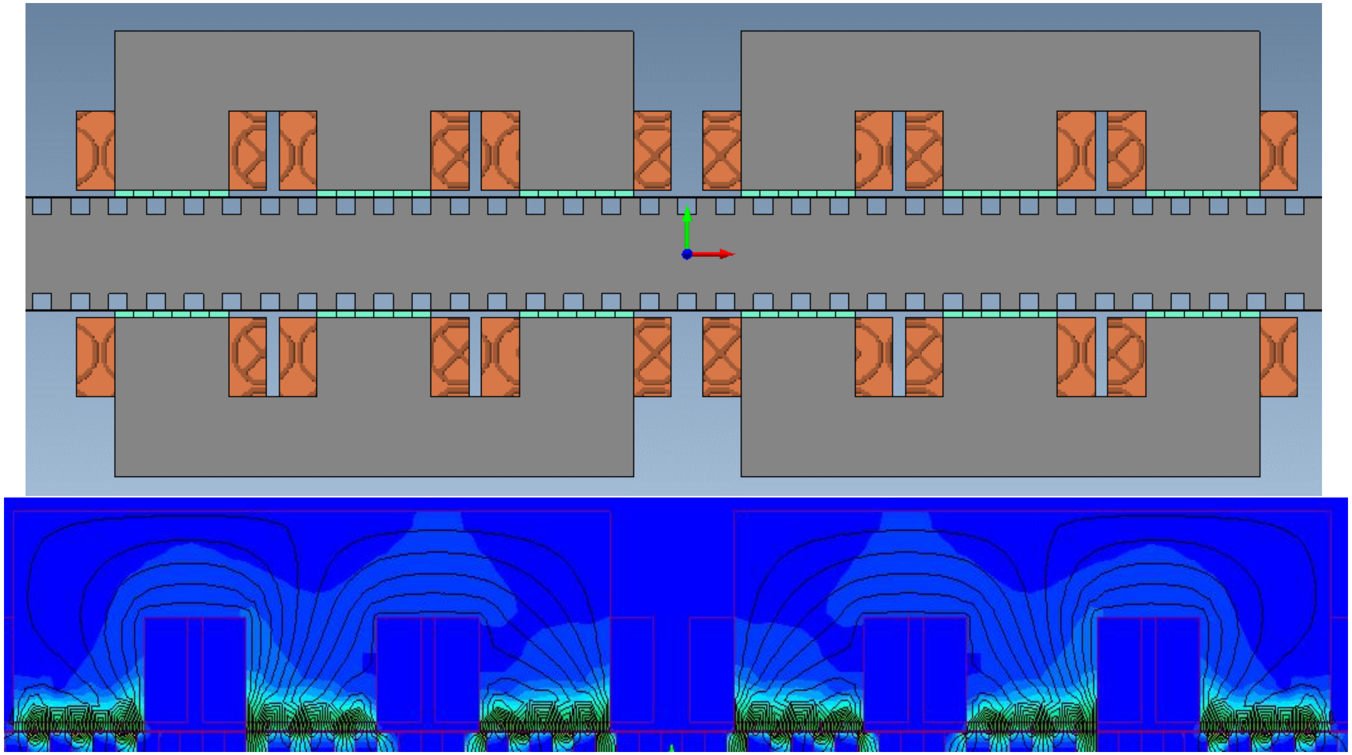
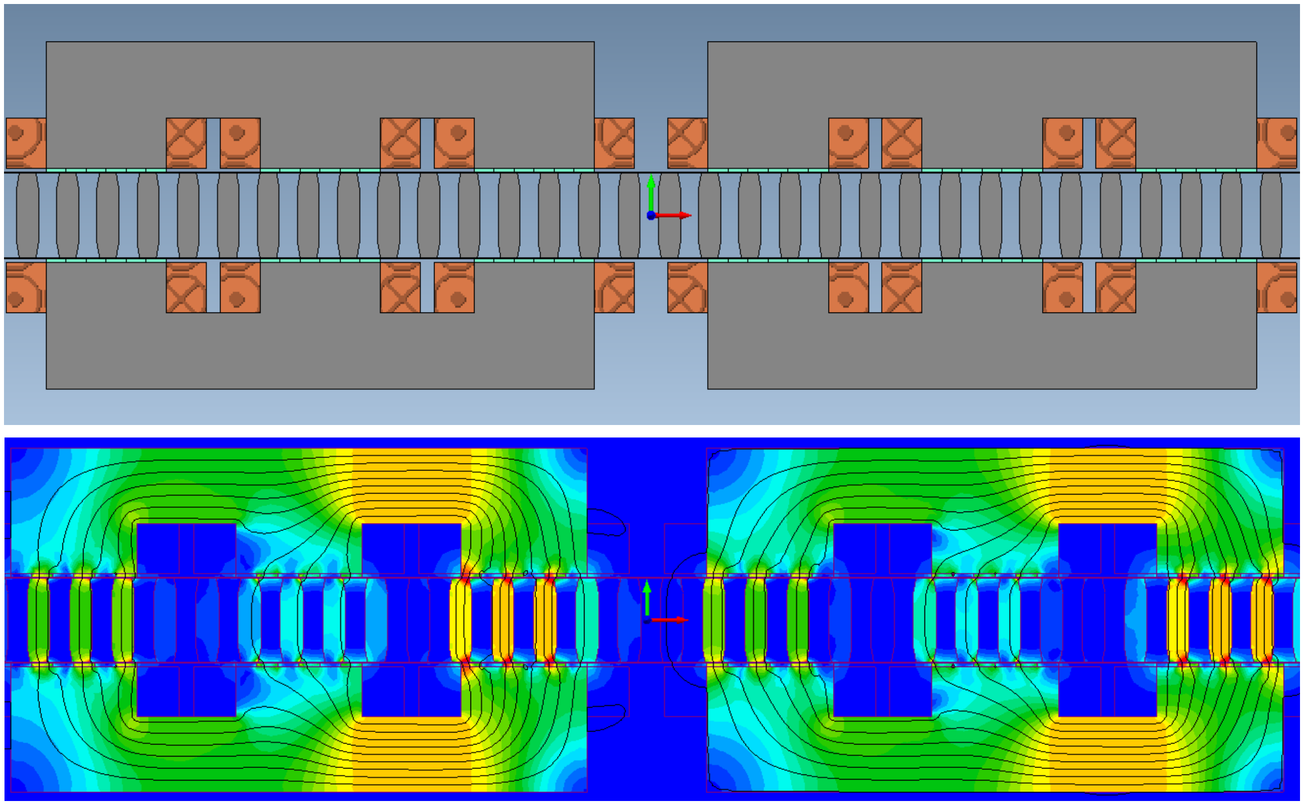
Electrical machine design work

Integrated E-cores:

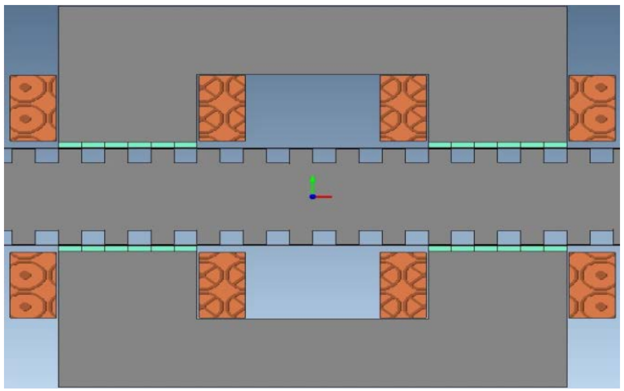


Electrical machine design work

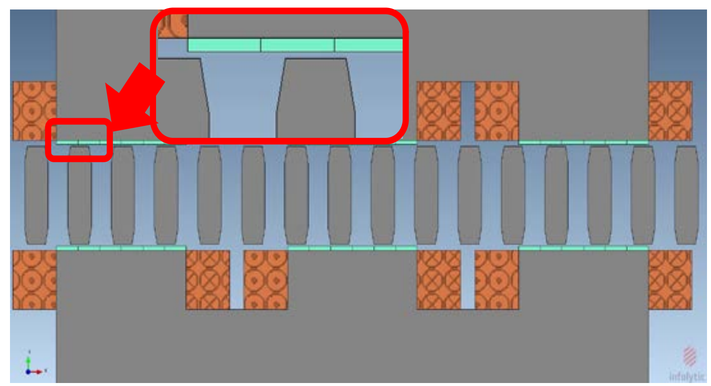
<u>Optimised integrated 3 phase model:</u>



- Linear Generator development:



Optimisation of model parameter and design



Amplitude amplification:

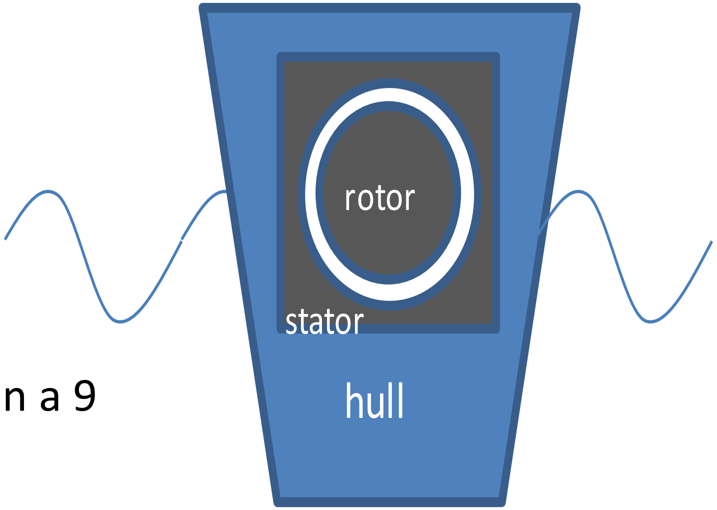
Amplification	*2*	*1*	
Force	80.0	160.0	kN
Amplitude	10.0	5.0	M
Units	3.0	6.0	
steel (translator)	1.22	0.94	tonne
steel (stator)	0.97	1.95	tonne
steel (total)	2.2	2.9	tonne
Copper	0.23	0.46	tonne
Magnet	20.1	40.2	Kg
axial length	0.5	0.5	M
active length	2.1	4.2	M

Amplitude amplification:

- The active mass of the stator decreases and the active mass of the translator increases with amplification. In total, the amplified version gives a saving on all materials. Amplitude amplification is beneficial in this situation.
- The potential active mass reduction associated with amplitude amplification is potentially offset by an almost linear increase in mass of translator with stroke length. There is no such limitation in a rotary machine, where machine mass is constant regardless of oscillation magnitude.

Case Study 2: A large pitching device- constant frequency

- Large device (Hull) with sufficient ballast
- Oscillating at own f_o regard less of PTO force
- 100m by 30m hull (similar to a ship)



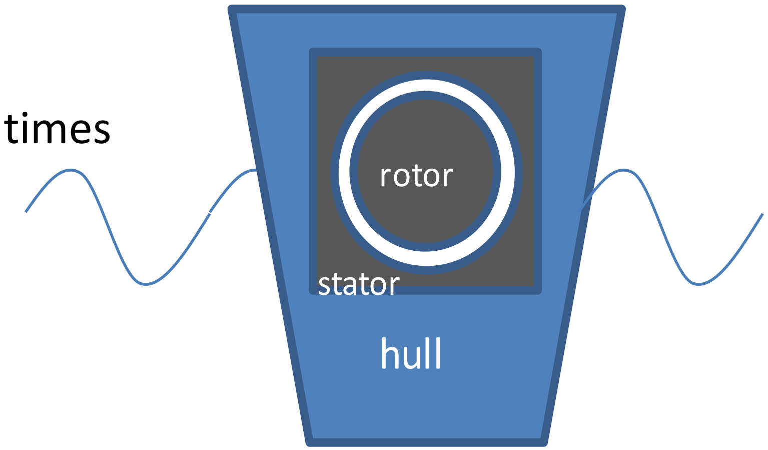
Basic power take off:

- Oscillation of hull considered constant
- **1MW** peak from a hull pitching +/-8 degrees in a 9 second period,
- Peak torque of **10 x 10^3 KNm** (1 per unit)
- Rotor coupled to stationary inertial reference frame

Case Study 2: A large pitching device- constant frequency

Introduce a spring (Resonant System):

- Amplify relative displacement by 12 times
- Reduction of peak torque to **800kN**
- Damping coefficient, B_{pto}=0.005
- J = moment of inertia, K=spring constant

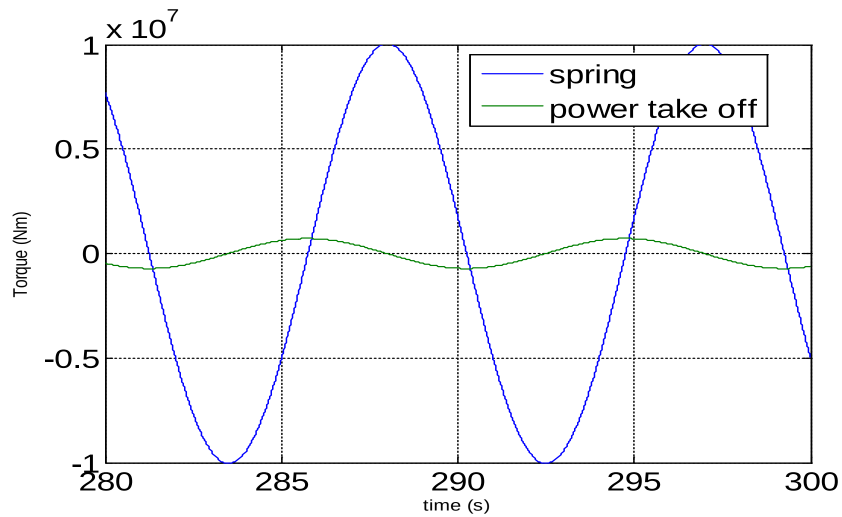


$$\ddot{\theta}_2 = \frac{1}{J}\left[B_{pto}\left(\dot{\theta}_1 - \dot{\theta}_2\right) + k\left(\theta_1 - \theta_2\right)\right]$$

Case Study 2: A large pitching device- constant frequency

The perfect spring….

- Spring torque >> PTO torque (Rated machine torque)
- Saving of machine torque → comes in expense of larger spring torque
- Amplitude amplification can only Reduce the Peak machine torque if spring force are applied externally.



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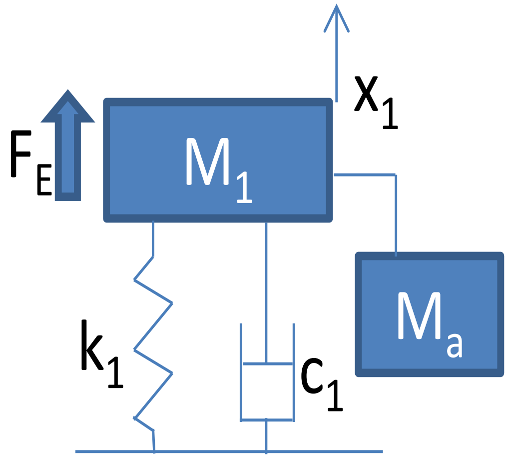
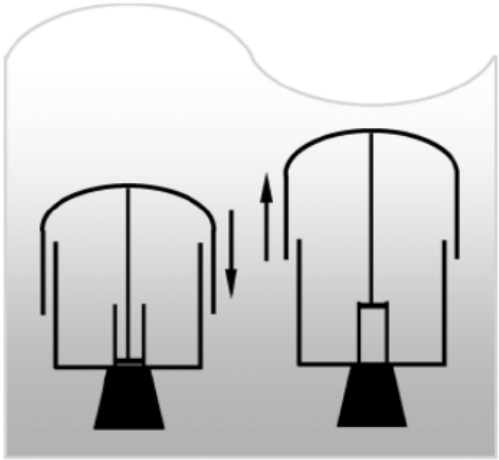
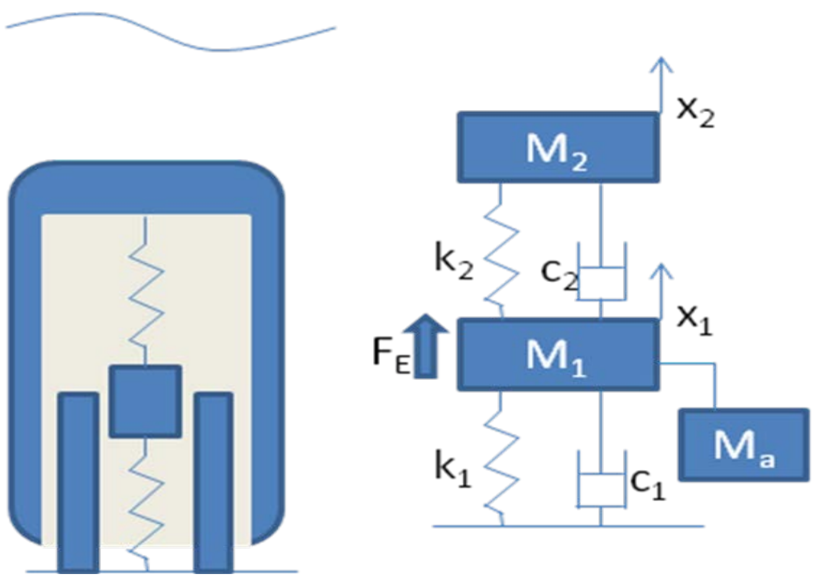
Case study 3: Excited Archimedes Wave Swing (AWS)

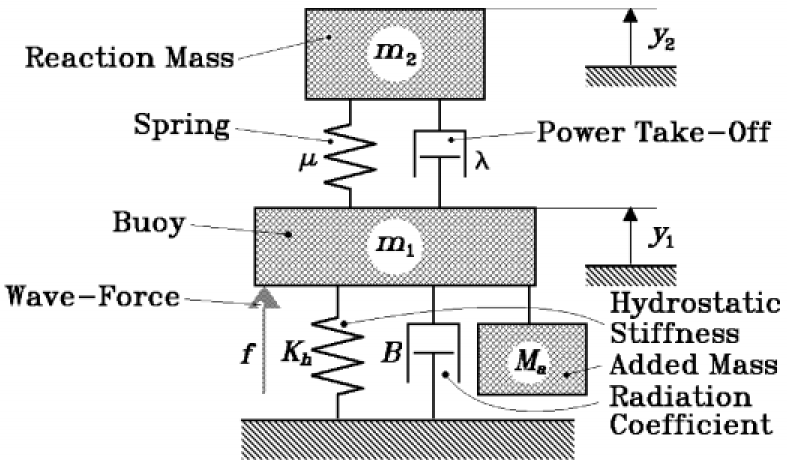
- AWS consist of oscillating hood (air pocket inside act as pneumatic spring) coupled with a linear generator.
- AWS can be modelled in steady state by a simple mass-spring system.





Amplitude amplification in AWS - Spring mounted PTO AWS





Linearised FROG Model

$$\ddot{x}_2 = \left(C_2(\dot{x}_1 - \dot{x}_2) + k_2(x_1 - x_2) - m_2 g\right)\frac{1}{m_2}$$

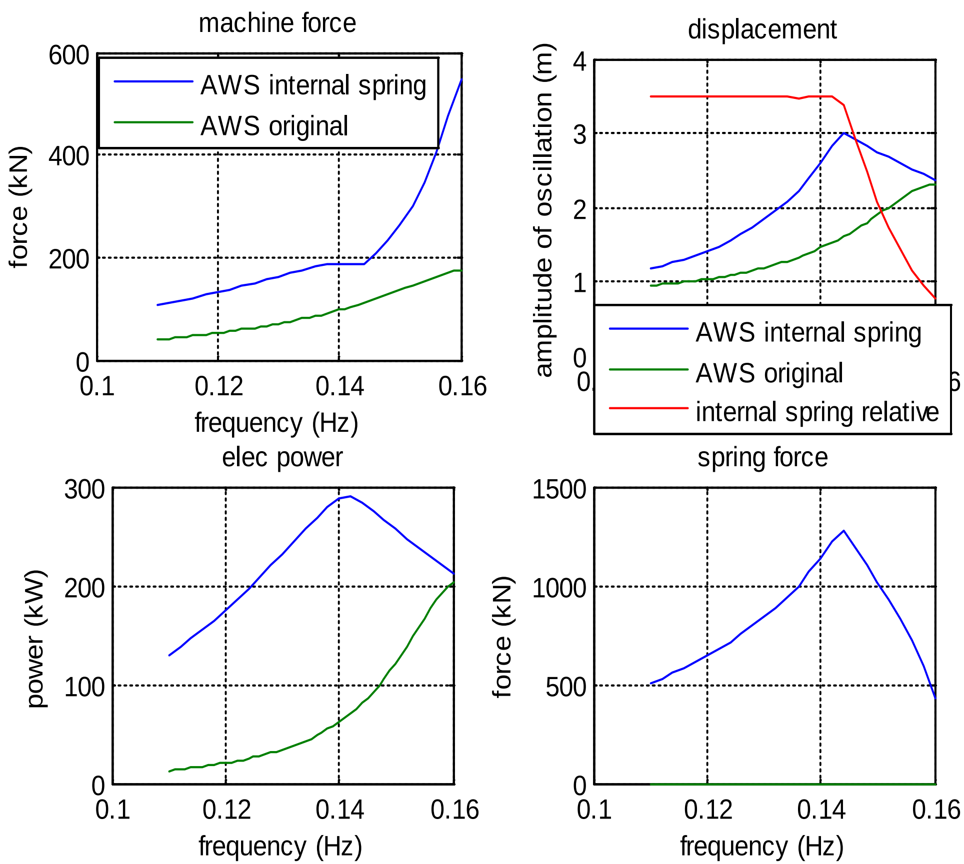
$$\ddot{x}_1 = \left(F_E \sin \omega t - k_2(x_1 - x_2) - B_2(\dot{x}_1 - \dot{x}_2) - x_1 k_1 - \dot{x}_1 C_1 - m_1 g\right)\frac{1}{m_1 + m_a}$$

Amplitude amplification in AWS

- Higher power can be obtained from the new model at high frequencies.

- Additional spring force >> required power take off.

- It does not make sense to add the spring force by the electric power train in this case study.



Contents

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Conclusion

- Electrical PTO system
- Performance of VHM improved.
- 3 case studies presented
  - Case 1: Amplitude amplification was advantageous even in linear machines.
  - Case 2 : Adding the spring can induce resonance, increase velocity and reduce the force rating of the power take off. However, the spring force can be many times greater than the power take off force and only advantageous if is supplied externally.
  - Case 3: Introducing additional spring can favour amplitude amplification while higher spring force offset all the machine gains.

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Thank You!

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