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New Type of Linear Switched Reluctance Generator for Wave Energy Applications

L. García-Tabarés, M. Lafoz, M. Blanco, J. Torres, D. Obradors, J. Nájera, G. Navarro,

CIEMAT

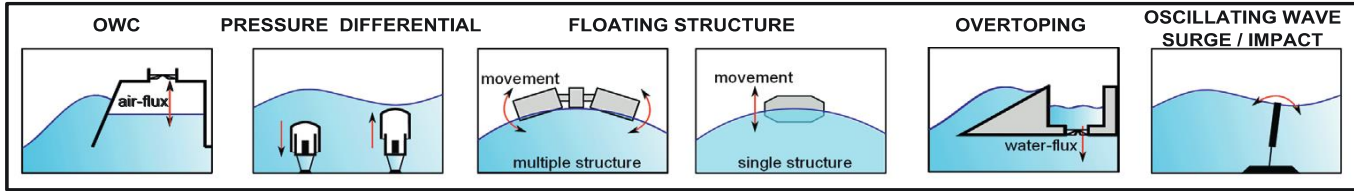
F. García, A. Sánchez

WEDGE GLOBAL



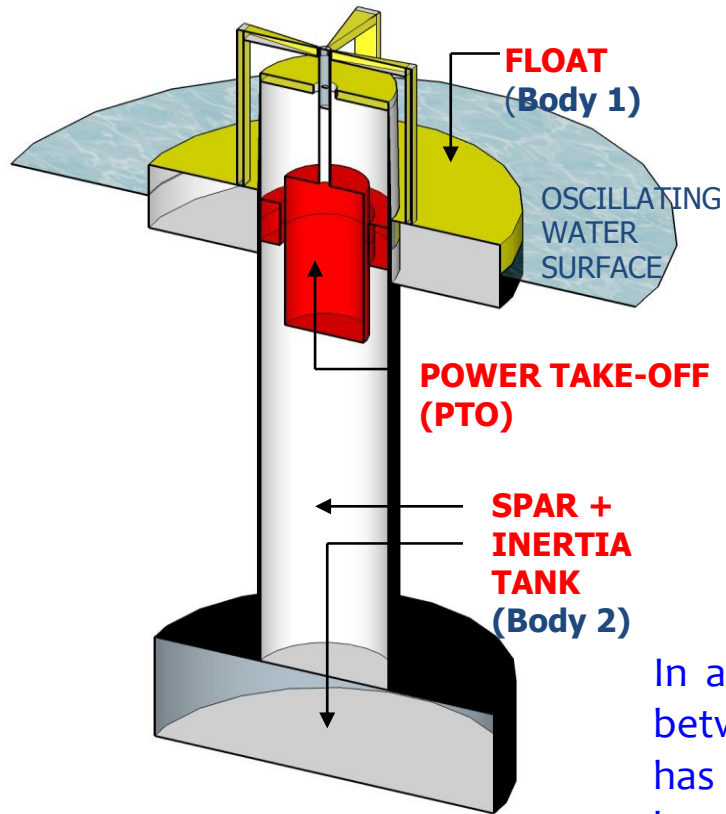
The World of Wave Energy Converters

WORKING PRINCIPLE



| | | | | | | | |
|----------|-----------|---|-------------------------------|------------------------------------|--------------------------------------|---|-----------------------------------|
| LOCATION | ONSHORE | <p>Attenuator Point Absorber Terminator</p> | | | | | |
| | NEARSHORE | <p>Limpet WaveGen (UK)</p> | | | | <p>SSG WAVEenergy (NO)</p> | |
| | OFFSHORE | <p>Oceanlix Energetch (AU)</p> | <p>CETO III REH (UK)</p> | <p>WaveStar Wave Star (DK)</p> | <p>Seareaser Energy (UK)</p> | <p>Waveplane Waveplane (DK)</p> | <p>Oyster Aquamarine (UK)</p> |
| | | <p>OE Buoy Ocean energy (IRL)</p> | <p>AWS AWS Ocean (UK)</p> | <p>Pelamis PWP (UK)</p> | <p>UNDIGEN Wedge Global (ES)</p> | <p>Wave Dragon Wave Dragon (DK)</p> | <p>Langlee LWP (NO)</p> |
| | | Terminator | Point absorber | Atenuattor | | | |

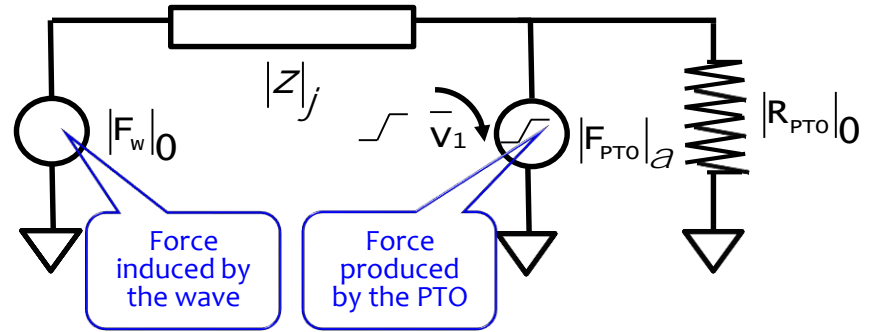
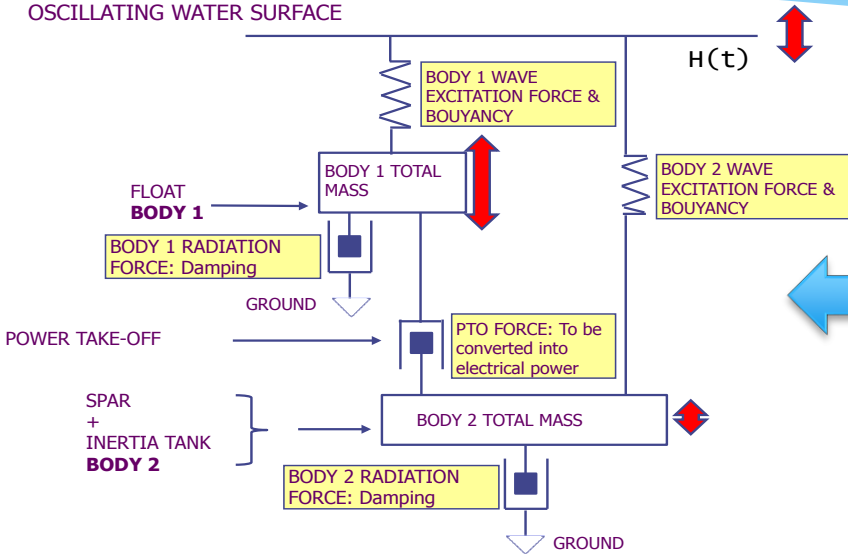
The Heaving Point Absorber (HPA) Type WEC



In a HPA the energy is produced from the relative displacement between the two bodies in the Power Take-Off. A Point Absorber has a small dimension compared to wave length and is able to harvest energy from any wave direction.

The Physics of Point Absorbers

OSCILLATING WATER SURFACE



A Point Absorber is an oscillating system with a corresponding mechanical model, which can also be expressed in terms of the equivalent electric circuit. The circuit allows an easy determination of the required force at the PTO to extract the maximum energy from the wave.

The SEA TITAN Project

GOALS:

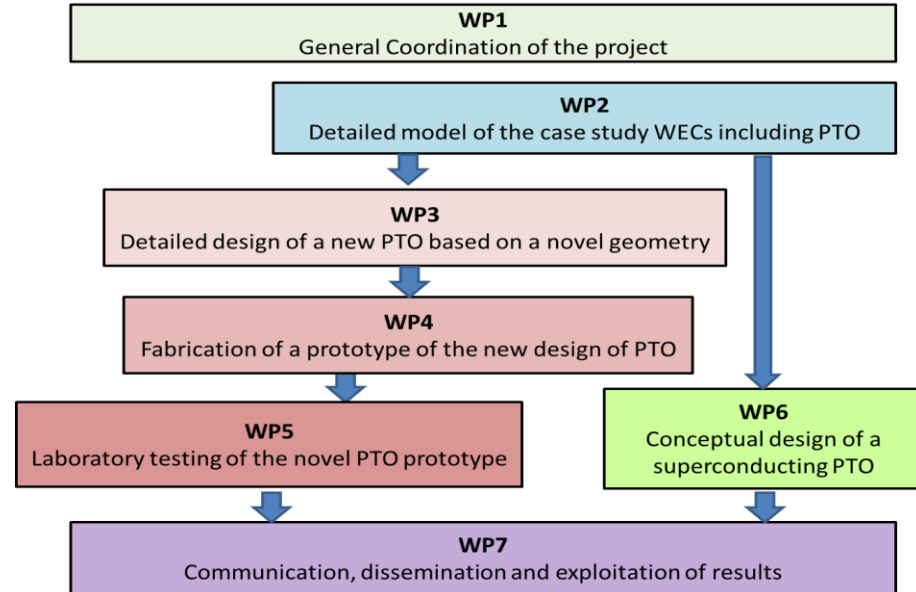
- Development of a new type of PTO based on SRM

- Force Density x 2
- IPCR x2
- FtWE up to 80%
- Capex/kW down by 25%
- LCoE down by 30%

- Modularity & Crosscuting up to 500 kN & 3m/s

- 3rd Generation of superconducting PTOs

- Bussines models based on “open hardware models”



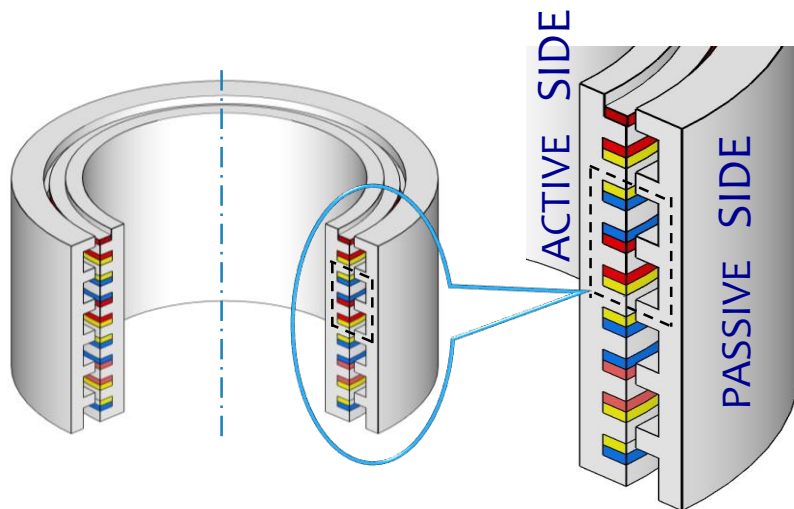
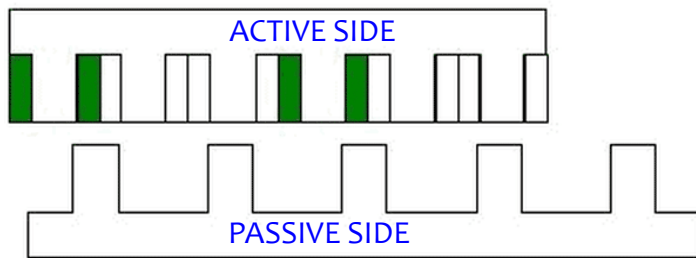
| | Participant Organization name | Type | Country |
|------|--------------------------------------|-------------------------|----------|
| 1(C) | Wedge Global S.L. | WEC Developer | Spain |
| 2 | CIEMAT | Public R&D Center | Spain |
| 3 | WavEC - Offshore Renewables | R&D Center | Portugal |
| 4 | CorPower Ocean | WEC Developer | Sweden |
| 5 | Centipod LTD | WEC Developer | UK |
| 6 | Hydrocap Energy SAS | WEC Developer | France |
| 7 | OCEM Energy Technology srl | Power Electronics | Italy |
| 8 | Columbus Superconductors (AGS) | Superconductors | Italy |
| 9 | Engie Fabricom | Installation & Services | Belgium |
| 10 | EDP Center New Energy Technologies | R&D Center | Portugal |
| 11 | Asociación Española de Normalización | Regulatory Body | Spain |



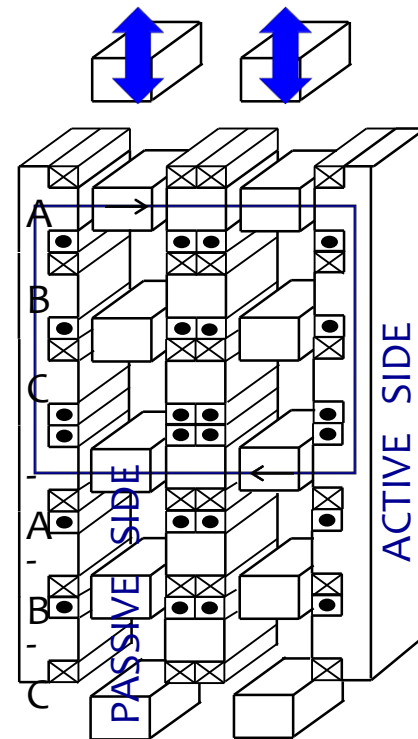
CENTIPOD LTD.



The Principles of the Switched Reluctance Machines

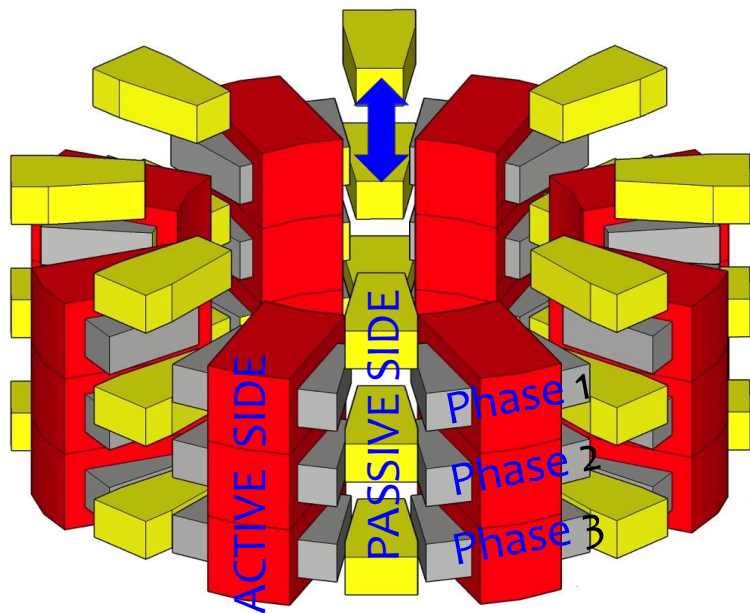


The CYLINDRICAL SINGLE-SIDED SRM

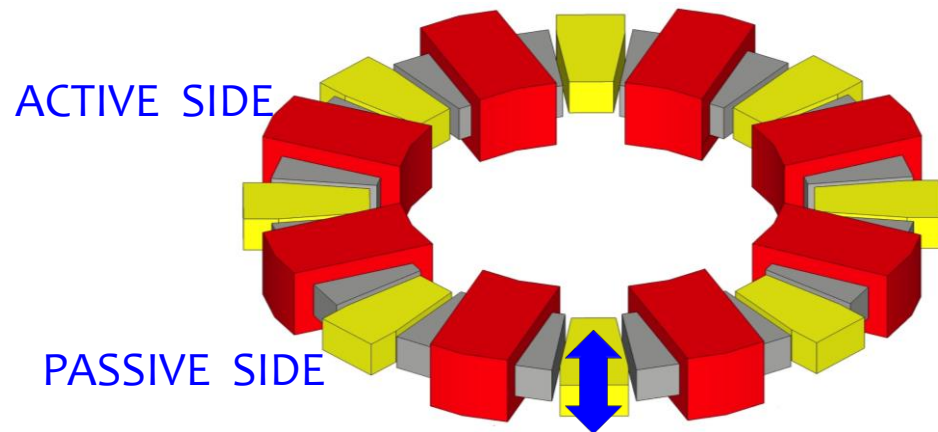


THE CONCEPT OF THE MULTITRANSLATOR
RECTANGULAR SWITCHED RELUCTANCE MACHINE

The Azimuthal SRM

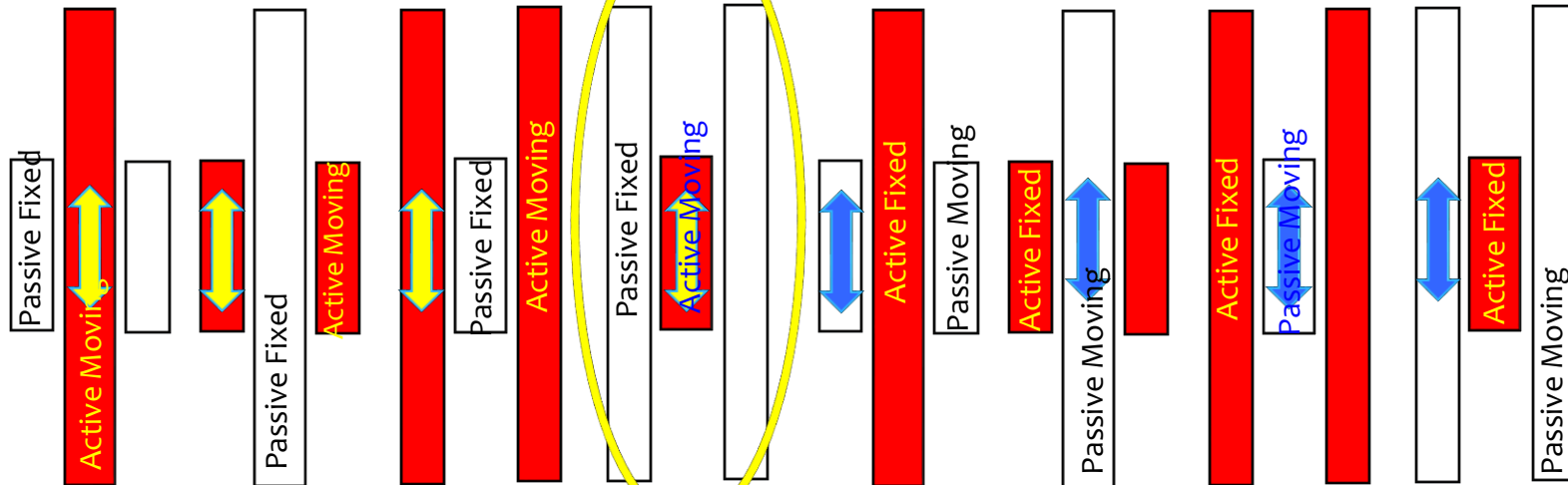
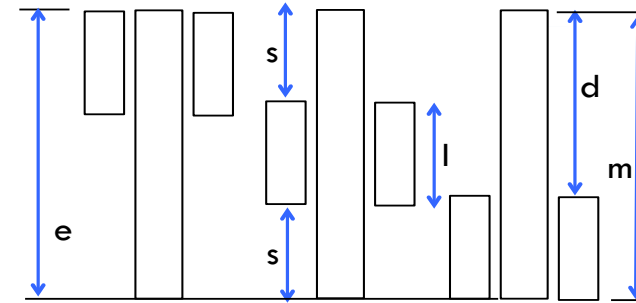
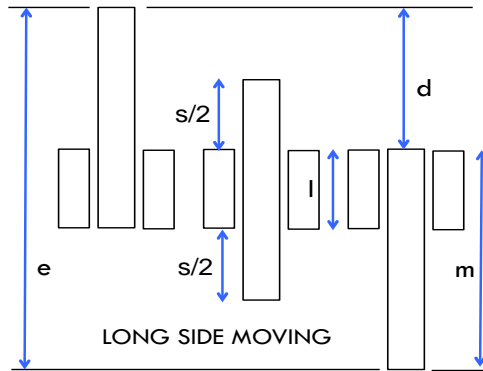


**The AZIMUTHAL SRM
(3-Phase Arrangement)**

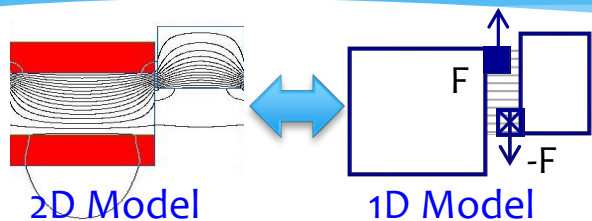


**The AZIMUTHAL SRM
(Detail of One Phase)**

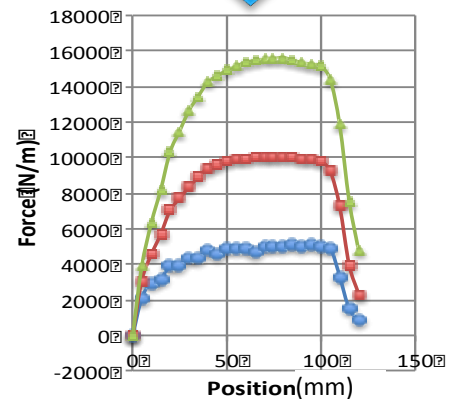
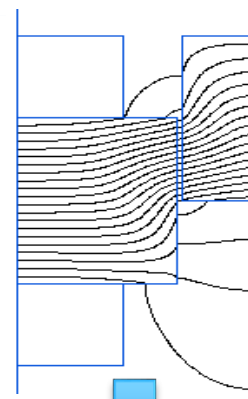
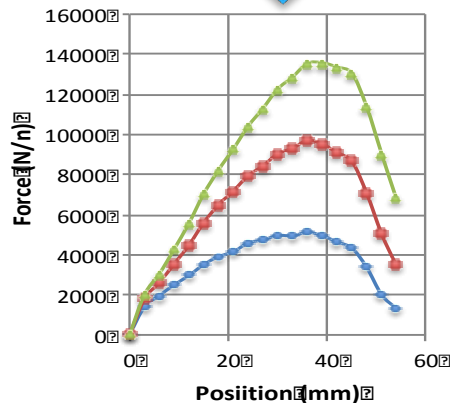
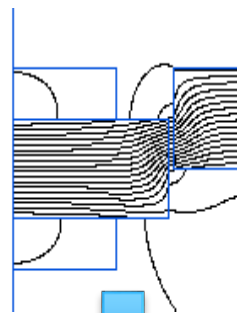
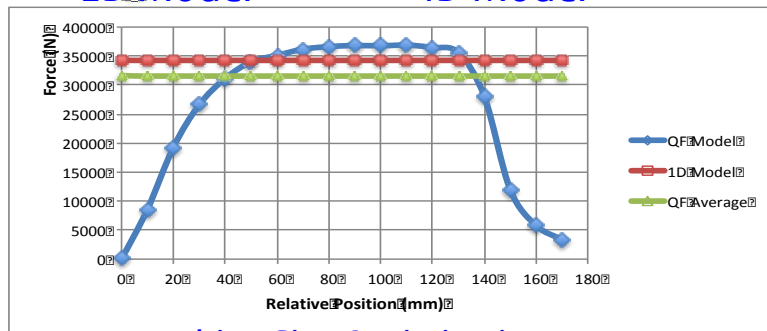
Configurations for the Azimuthal SRM



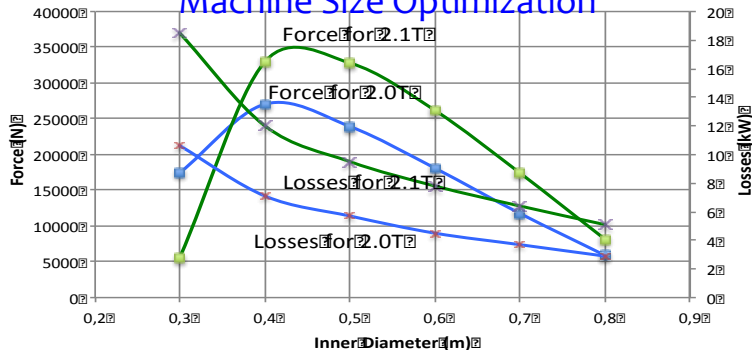
First Magnetic Calculations of the Azimuthal SRM



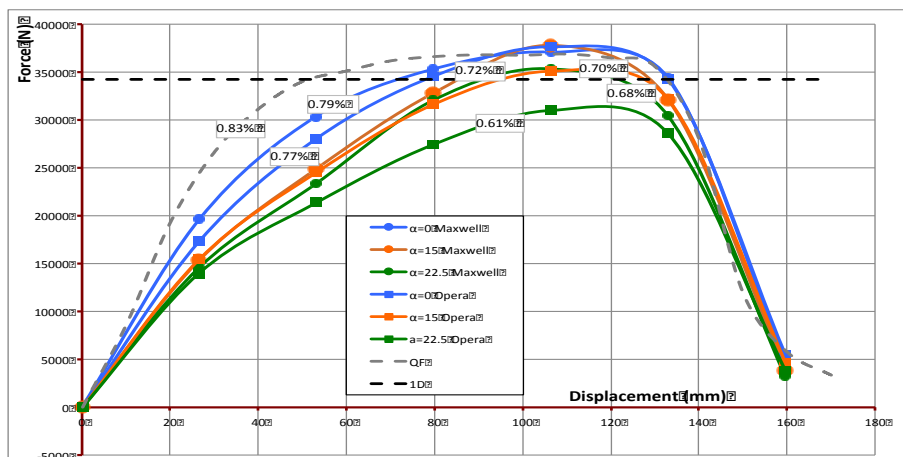
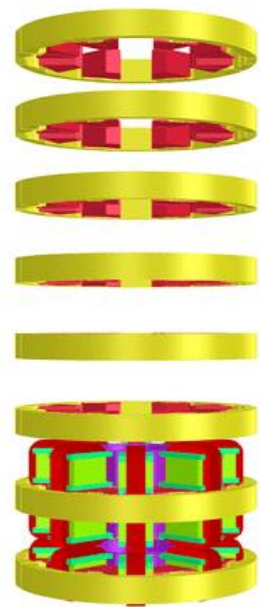
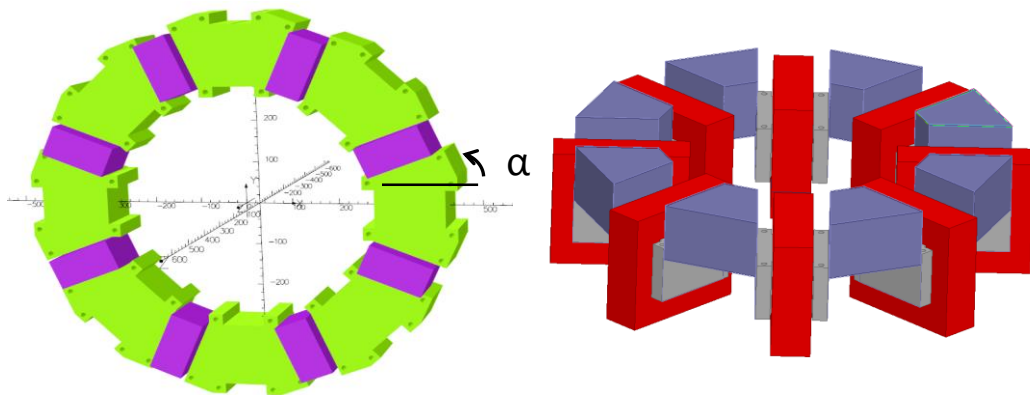
Coils Aspect Ratio has a great importance in the Force vs Position Curve



Machine Size Optimization



3-D Magnetic Calculations for the Azimuthal SRM



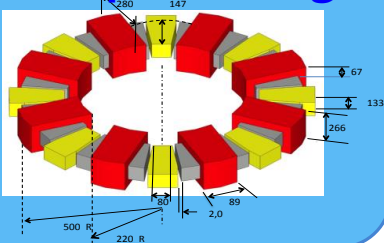
Force calculations using 3D codes have also been performed. The force evolution is very sensitive to the wedge angle of the poles.

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Complete Simulation of the Azimuthal SRM

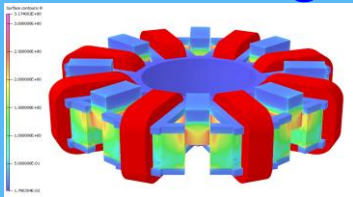
Conceptual & FEM Design

Conceptual Design



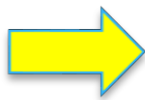
&

FEM Modeling



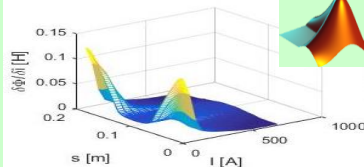
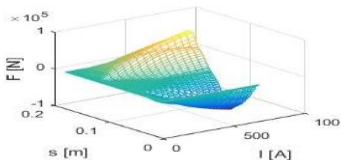
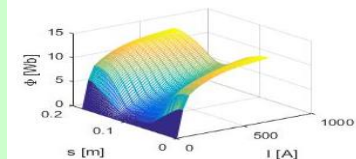
Opera
Simulation Software
COBHAM

ANSYS



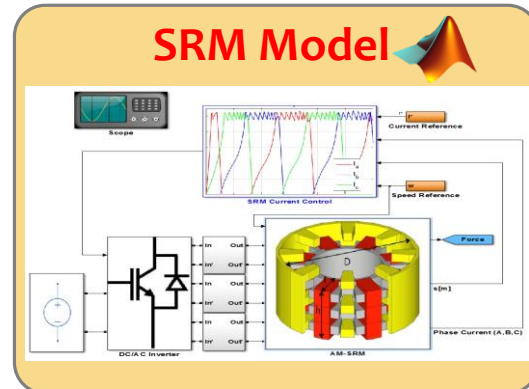
Flux & Force Tables

Postprocessing



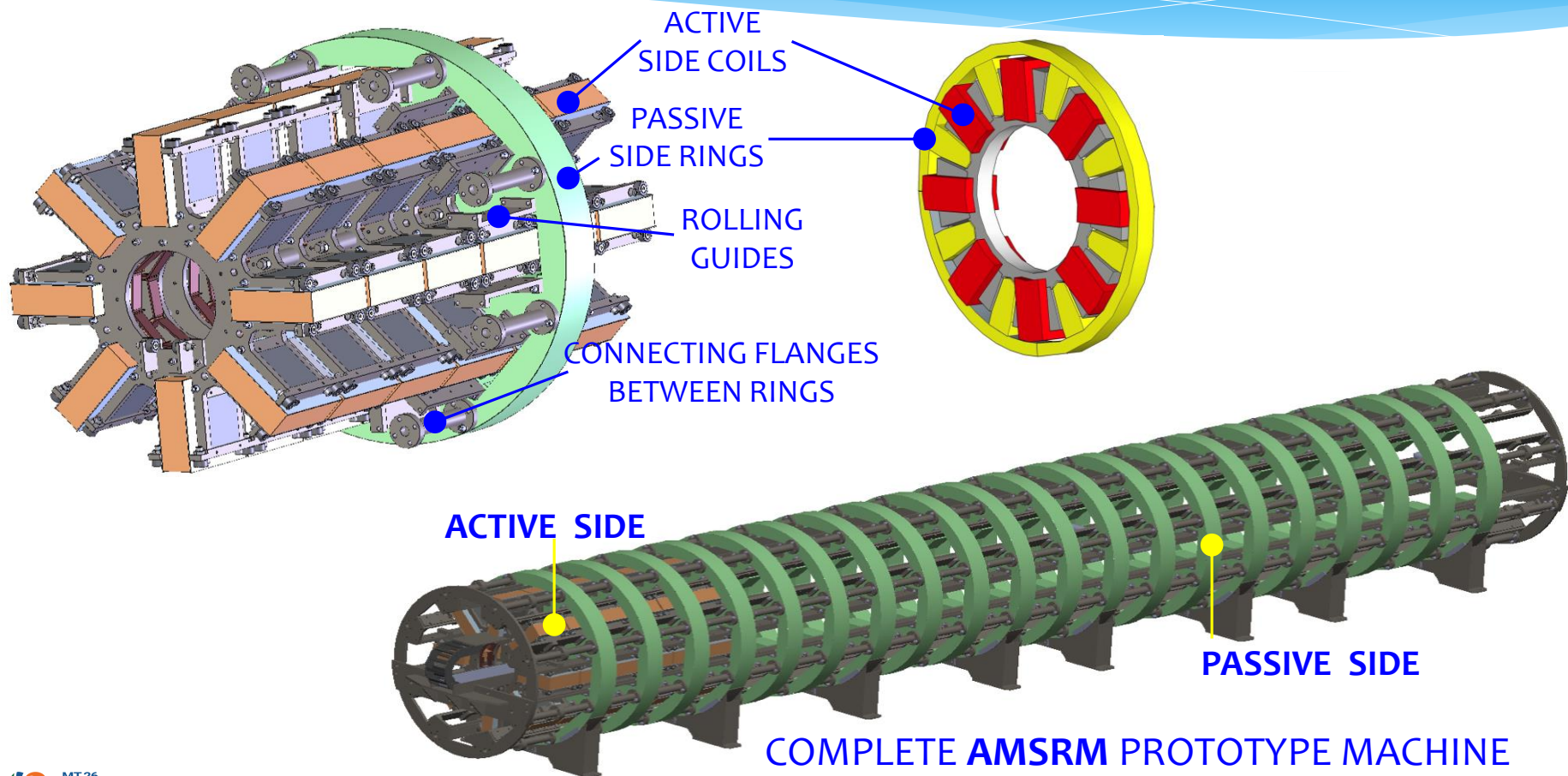
Matlab-Simulink Model

SRM Model



Current waveforms to design power electronics and power losses.

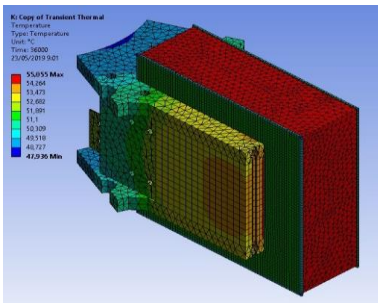
The Azimuthal SRM Prototype Overall Design



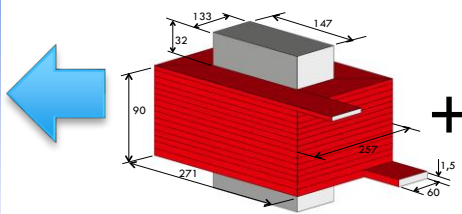
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 764014

The Azimuthal SRM Additional Calculations

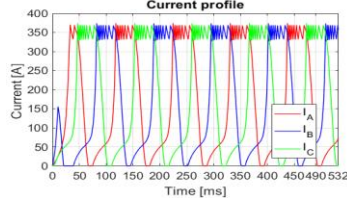
THERMAL CALCULATIONS



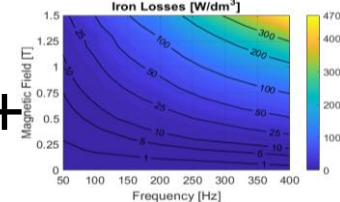
DC Joule Losses



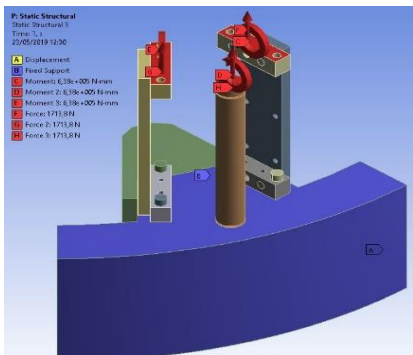
AC Losses



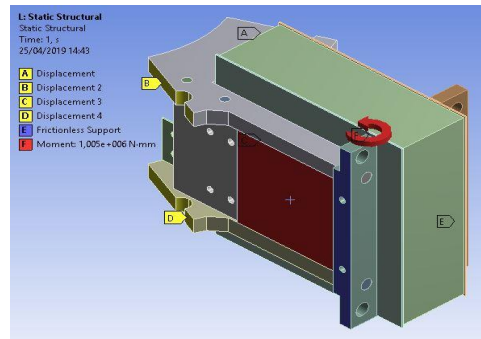
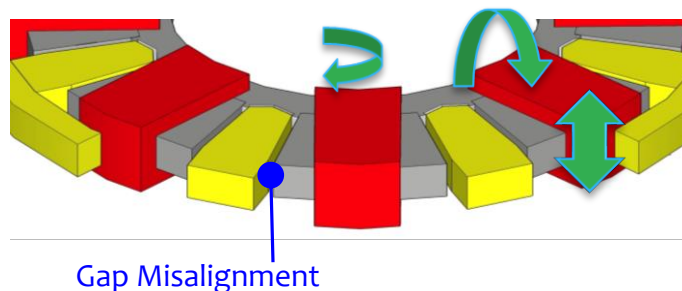
Iron Losses



MECHANICAL CALCULATIONS

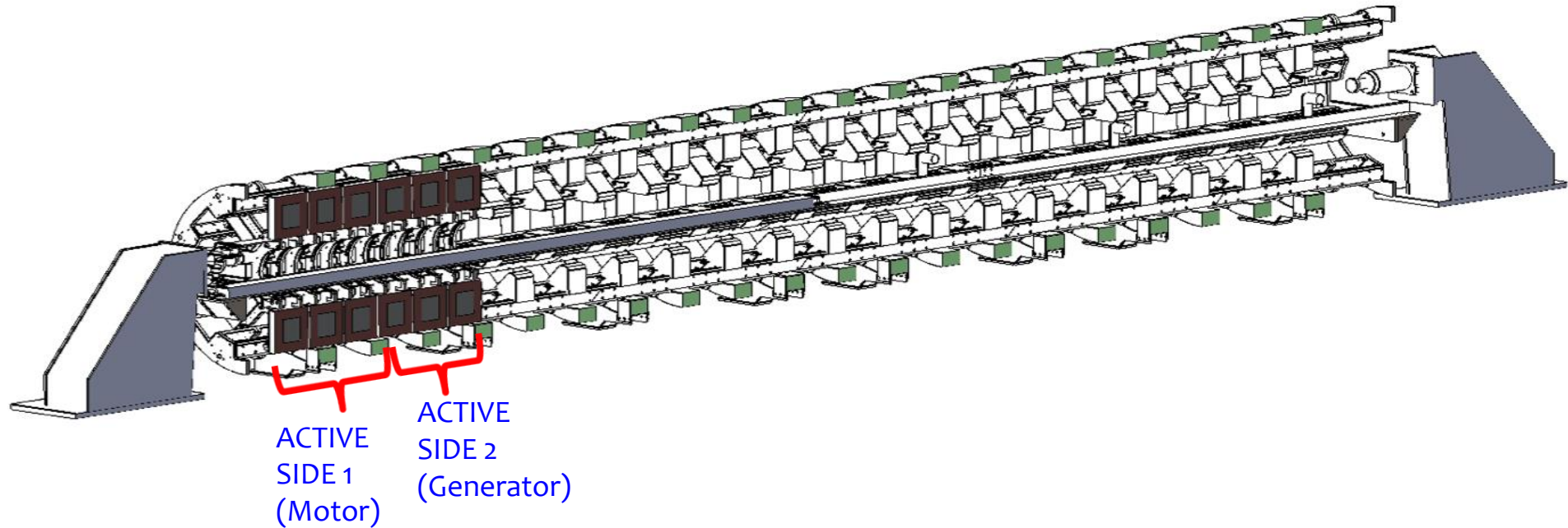


Stresses on the Passive Side



Stresses on the Active Side

Testing the Azimuthal SRM

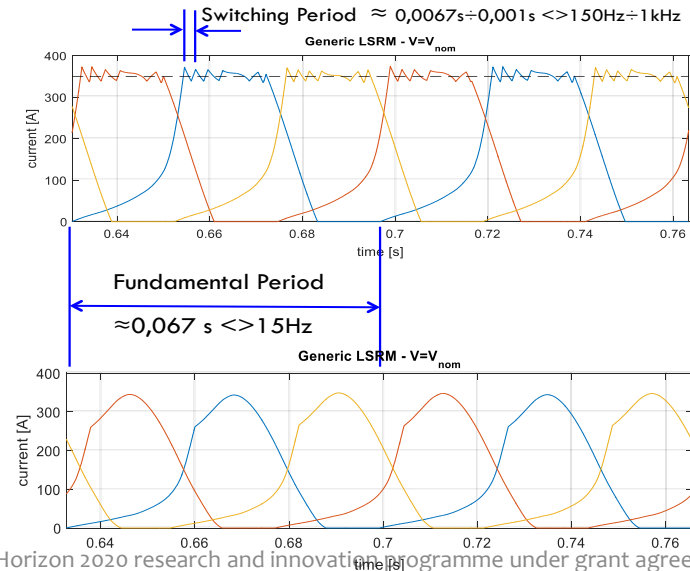
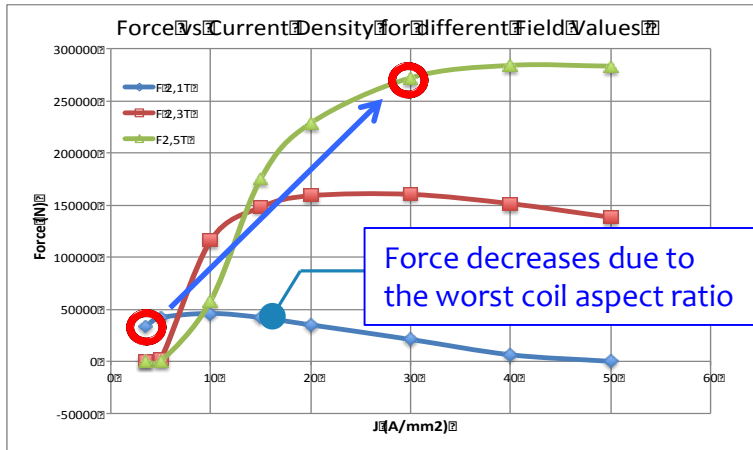
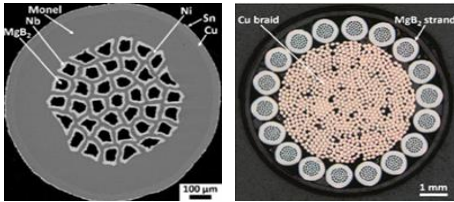
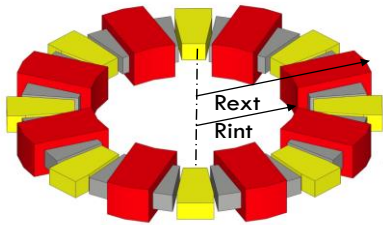


The PTO will be tested in a Back to Back configuration in which one of the machines acts as a generator and the other as a motor, both driven by an independent converter.

Towards a Superconducting Azimuthal SRM

A superconducting version of an AMSRM is theoretically attractive because:

- The machine has only one side with coils and this side can be stationary.
- Increasing the field from 2.1T to only 2.3 T and the current density from 5 Amm^{-2} to 30 Amm^{-2} would mean increasing the force by a factor of 8.
- MgB_2 can be an ideal candidate for the required levels of J & B , **BUT:** AC losses can be inadmissible high and this requires special wire configuration and different operation of the machine (Single-Pulse and not Multi-Pulse).



Summary & Conclusions

- Heaving Point Absorbers are consolidated candidates for WECs
- Their capability to harvest energy is increased by hosting high force PTOs
- PTOs must produce a “vector” force (controllable in magnitude & phase)
- In April 2018 started the Sea Titan Project to develop a new concept of PTO based on a linear Switched Reluctance Machine.
- This PTO is based on an Azimuthal configuration that saves iron and has a better adaptation to the WEC geometry.
- The main deliverable of the Project is a 70 kN, 3ms^{-1} prototype to be tested horizontally at CIEMAT premises.
- This prototype has been magnetically, mechanically and thermally calculated and its design is practically finished.
- Additionally, Sea Titan considers the conceptual design of a superconducting version based on Mg B₂.

THANK YOU VERY MUCH !!!!!