HTS APPLICATIONS FOR ENERGY:

Magnetic Energy Storage
&
Ocean Energy Conversion

Luis García-Tabarés
CIEMAT

Industrial Workshop on HTS Developments & Applicatios

TRIESTE April 18th 2023

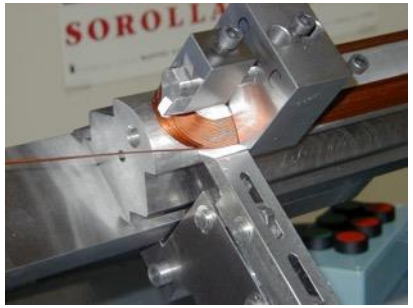
CIEMAT Presentation

CIEMAT is a Governmental Laboratory (Research Public Institution of the Ministry of Science & Innovation). With 1300 engineers, researchers and staff & 100 M€ annual budget. CIEMAT is divided in 5 technical departments including the Technology Department where the Division of Electrical Engineering is ascribed. This Division has been involved in applications of Power Superconductivity for more that 30 years.

TUNING QUAD FOR LHC

SMES FOR ASINEL

MQTL FOR LHC



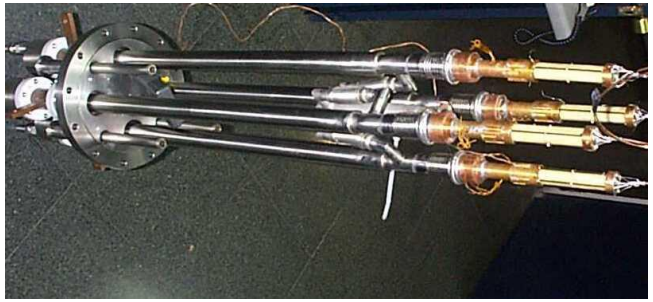
MgB_2 COILS FOR TECNALIA

MCBXFA&B FOR HL-LHC THE PRISMAC PROJECT

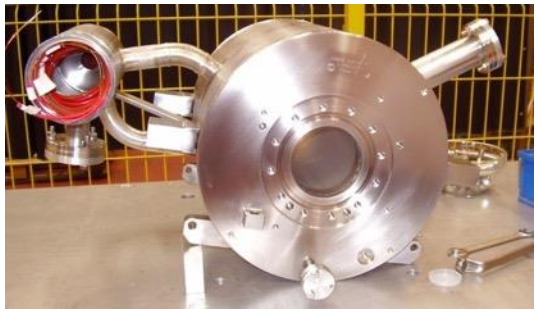
1990 2000 2010 2020

LHC CORRECTORS

Nb_3 Sn SOLENOIDS



BSCO 2212 CURRENT LEADS FOR LHC



QUAD & DIPOLES FOR EXFEL

CYCLOTRON AMIT & CREATION OF CYCLOMED

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Relevant Applications of Superconductors

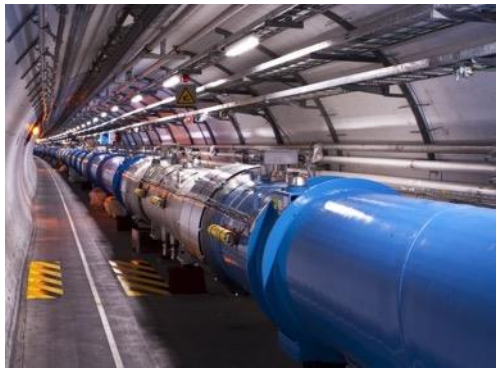
MEDICAL

MRI

Accelerators

SCIENCE

NMR



HEP Accelerators

ENERGY

Storage

Transmission

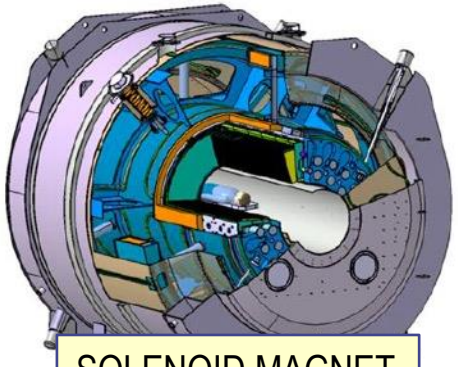
Generation

TRANSPORT

Maglev

Relevant Applications of Superconductors

MEDICAL



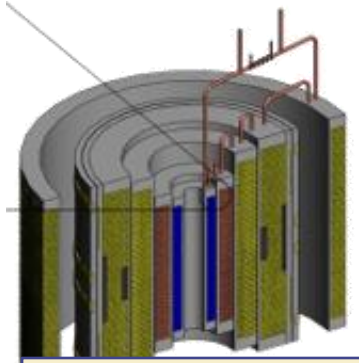
SOLENOID MAGNET

MRI

SOLENOID MAGNET

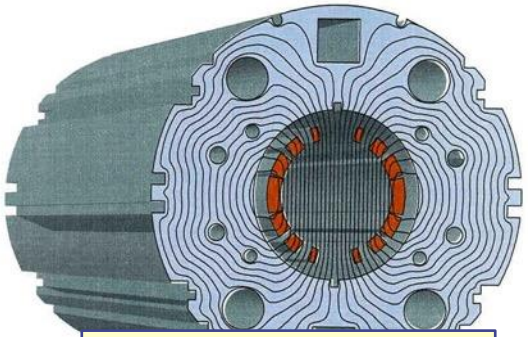
Accelerators

SCIENCE



SOLENOID MAGNET

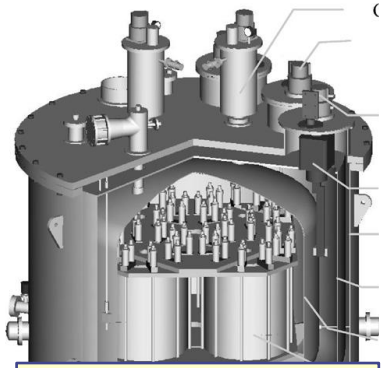
NMR



DIPOLE MAGNET

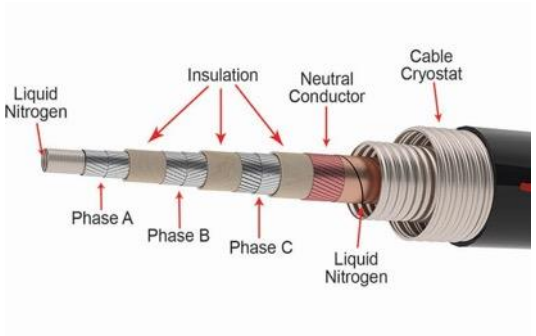
HEP Accelerators

ENERGY

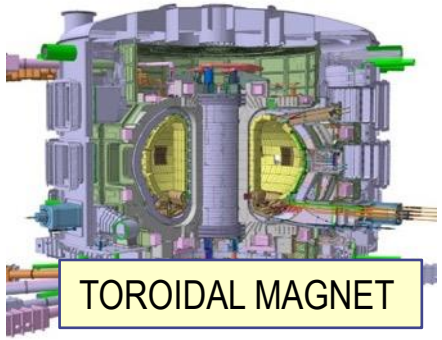


SOLENOID MAGNET

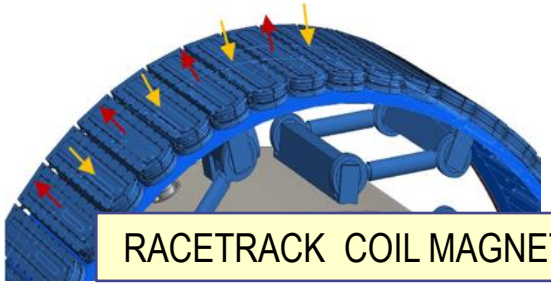
Storage



Transmission



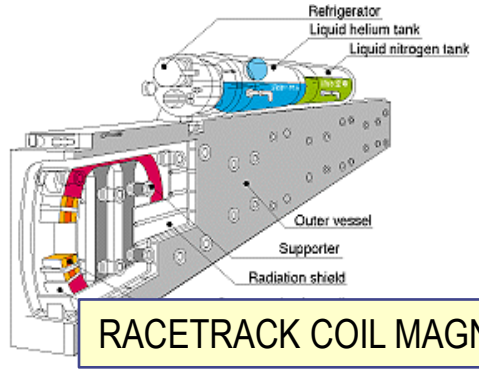
TOROIDAL MAGNET



RACETRACK COIL MAGNET

Generation

TRANSPORT



RACETRACK COIL MAGNET

Maglev

Development of HTS SMES for Waterborne Transport Applications

The need & benefit of Energy Storage On-Board

RIVER FERRY

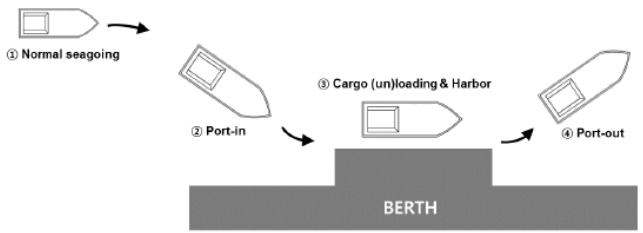
Mission: 126 crossings per day of the Seine. Only 3 minutes between crossings, and 3-30 minutes stops the rest of the day.

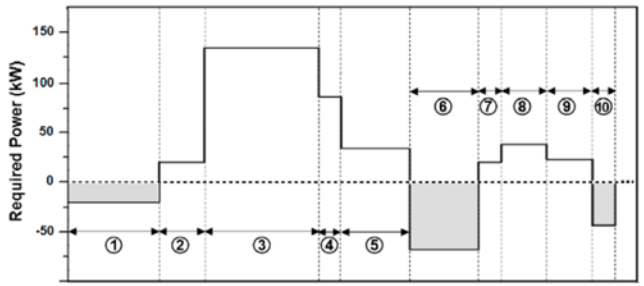
To substitute propulsion **ESS needs: 60kW, 5MJ (84 s.)** (Diesel generator is maintained)

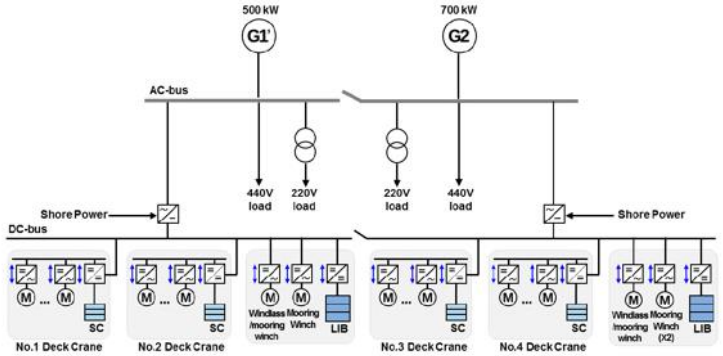
SCs: Can be recharged each trip (less investment), can withstand high number of cycles.

Batteries: Need to be sized for all-day operation. Charge during night, connected to power grid (additional investment)

BULK CARRIER







OVERALL

APLICATIONS ON-BOARD OF FAST RESPONSE ENERGY STORAGE SYSTEMS				
ENGINE STARTING				
DYNAMIC POSITIONING SYSTEM				
HIGH PEAK POWER DRIVE CYCLE	High Power disembarking & manoeuvring	Mid Power Acceleration	Low power cruise	High Power manoeuvring

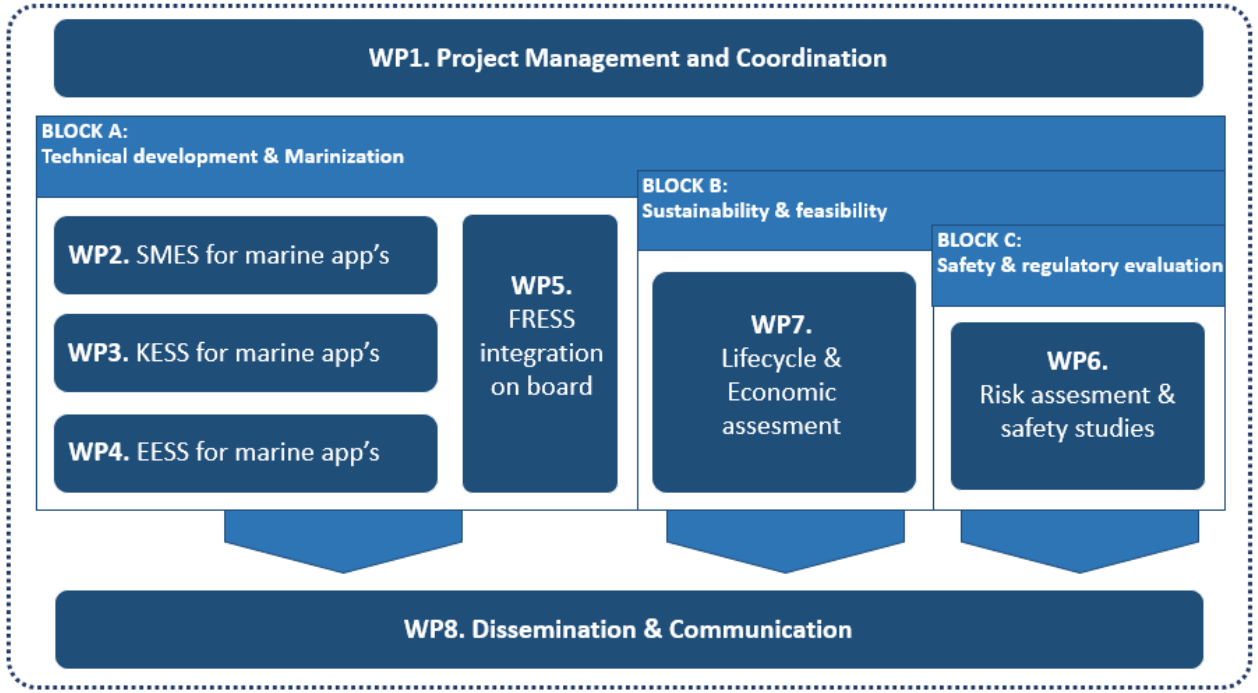
The POSEIDON Project

POwer StoragE In D OceaN

SCOPE & GOALS:

- Developing a SMES to be tested at the lab, based on a HTS Magnet
- Developing a KESS to be tested on board, based on a medium speed high strength steel flywheel.
- Developing a EESS to be tested on board, based on supercapacitors
- Defining a metrics for the Levelized Cost of Storage for ESS
- Defining the complementarity with other disruptive technologies in the sector.

Type of Action: RESEARCH & INNOVATION ACTION (RIA)
HORIZON-CL5-2022-D5-01

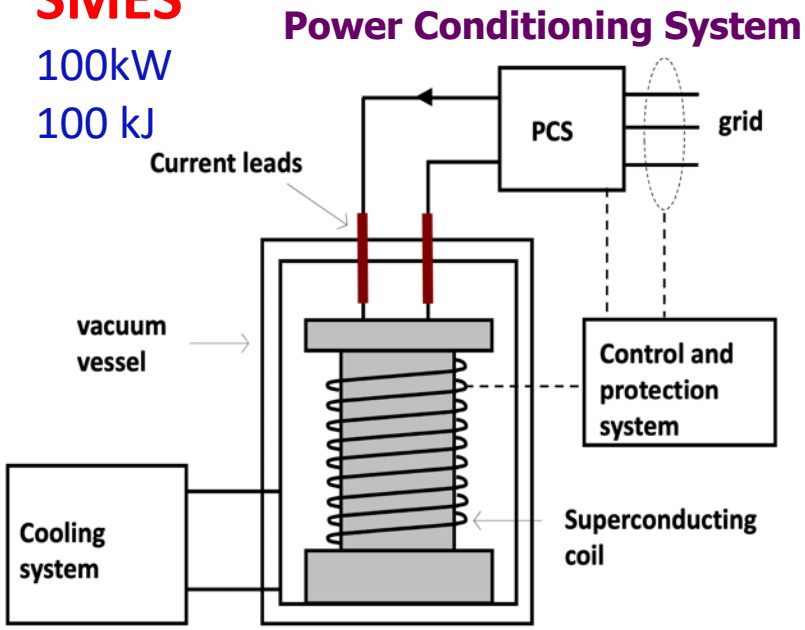


	Participant Organization name	Type	Country
1 (C)	Centro Tecnológico y Naval (CTN)	R&D Center	Spain
2	CIEMAT	Public R&D Center	Spain
3	EFESTO	Power Electronics Company	France
4	OCEM	Power Electronics Company	Italy
5	BALEARIA	Shipping Line	Spain
6	DAMEN	Shipyards	Nederland
7	CYCLOMED	Start-up	Spain
8	TECHNO PRO HISPANIA	Engineering Company	Spain
9	CERN	Public R&D Center	Switzerland
10	ANTEC MAGNETS	Magnet manufacturer	Spain
11	ANTECSA	Electric Company	Spain
12	Polytechnical University of Madrid	Public University	Spain

Three Energy Storage Systems On-board

SMES

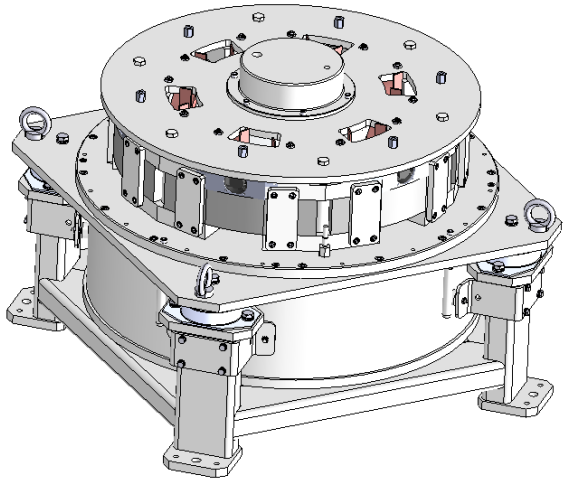
100kW
100 kJ



Based on HTS magnet cooled down with a He gas circulation system

KESS

25 kW
2.5 MJ



Based on a high strength steel flywheel and a Switched Reluctance Machine

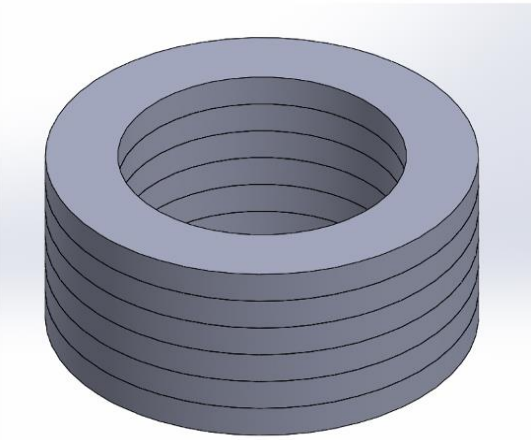
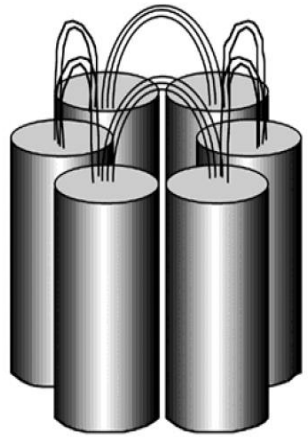
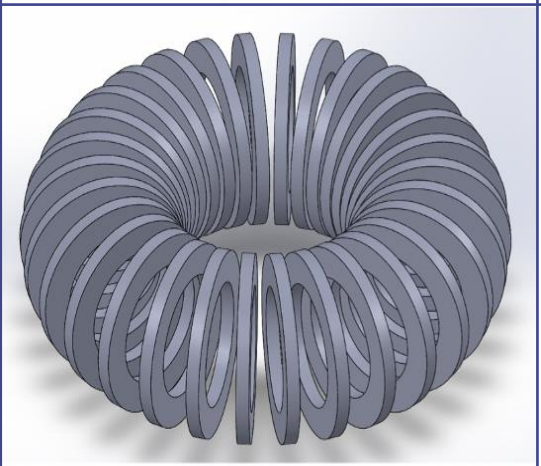
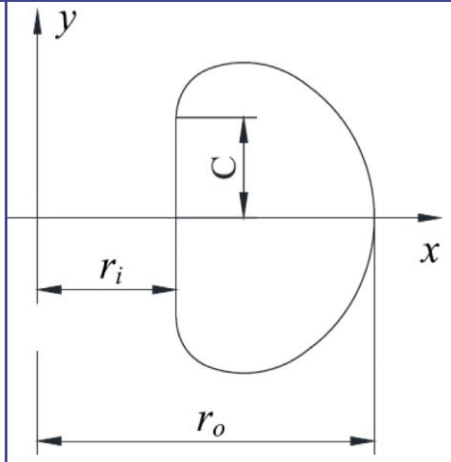
EESS

120kW
2.0 MJ

Based on an arrangement of Supercapacitors

+

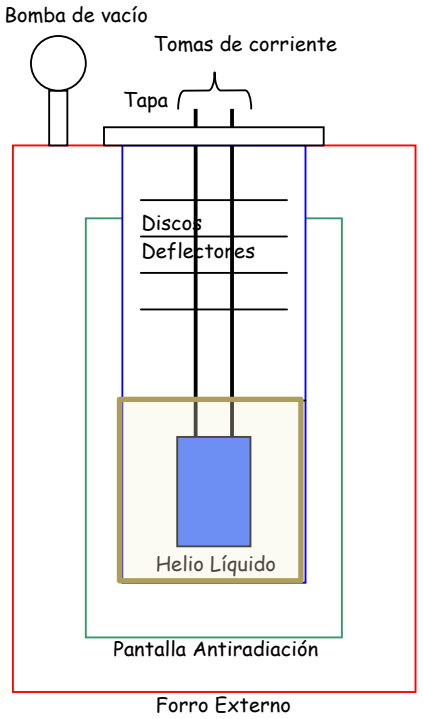
The Superconducting Modular Magnet: Options

	CONFIGURATION	ADVANTAGES	DISADVANTAGES	IMPROVED OPTIONS	
SOLENOID		* Simpler fabrication * Apparently, better energy density (Not clear for HTS) * Easier to manage Lorentz forces which are balanced	* High perpendicular B component at the coil ends > Lower J_c * High Stray Field, requiring active or passive shielding (Maritime Applications)	*Arrangement of multiple solenoids to reduce the Stray Field	
TOROID		* Very low stray field (Maritime Applications) * Magnetic field rather parallel to the tape * Filling the bore with iron can increase the energy significantly.	* Not compensated net coil Lorentz forces. * More difficult cryostating * Apparently less energy density (J/kg)	* D-shape coils to cancel the coil unbalance	

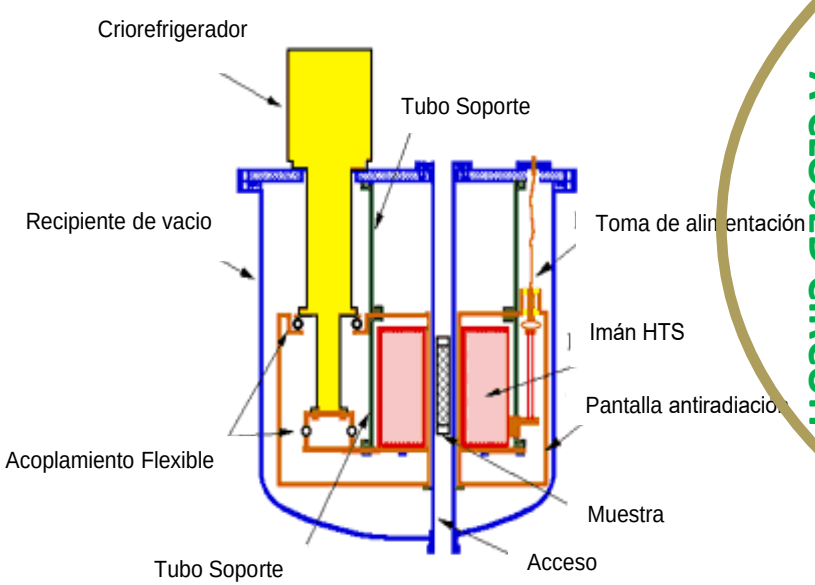
The Cooling & Power Conditioning Systems

COOLING SYSTEM OPTIONS

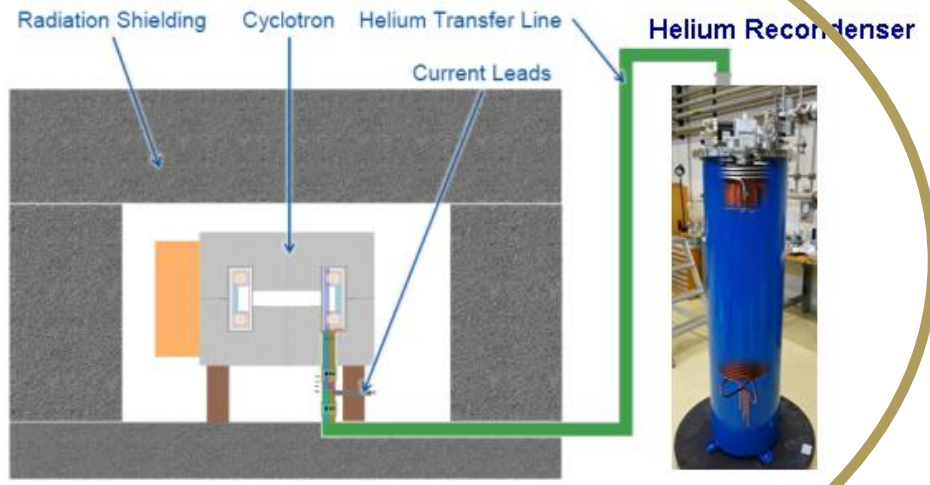
IMMERSION IN A LIQUID COOLANT



CONDUCTION COOLING WITH CRYOCOOLER

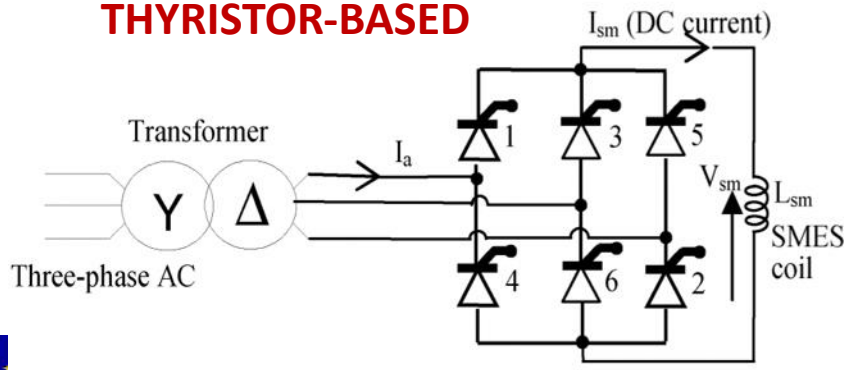


GAS CIRCULATION IN A CLOSED CIRCUIT

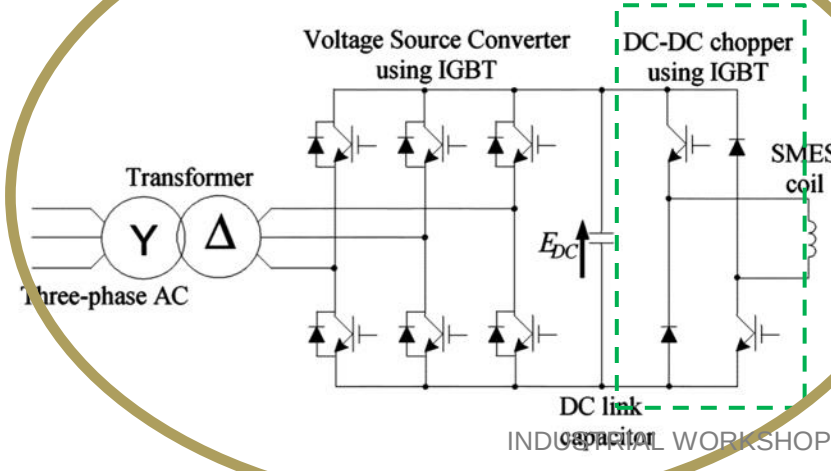


POWER CONDITIONING SYSTEM OPTIONS

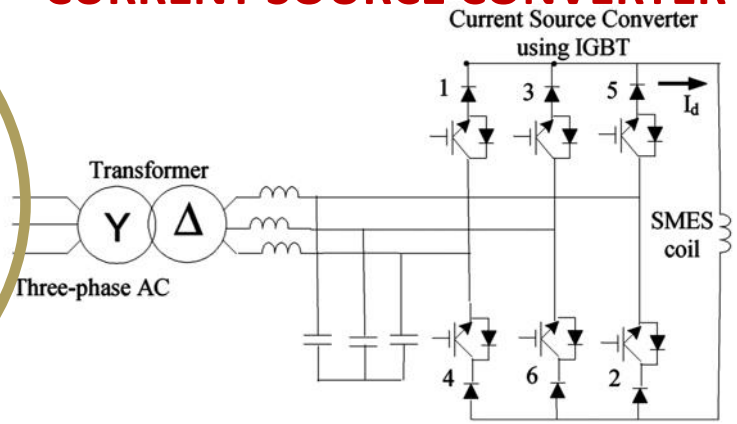
THYRISTOR-BASED



VOLTAGE SOURCE CONVERTER



CURRENT SOURCE CONVERTER

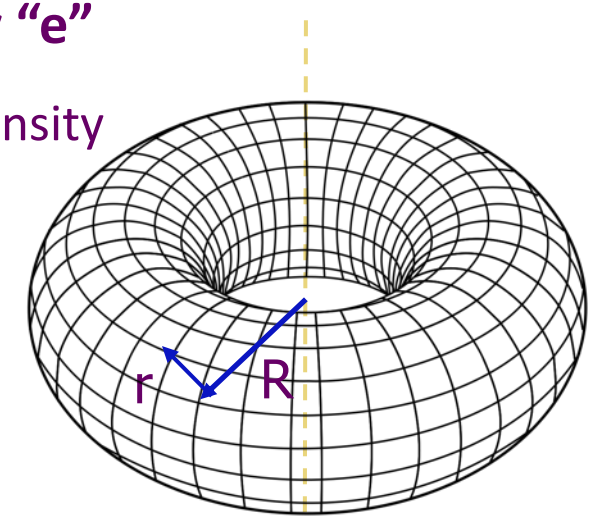


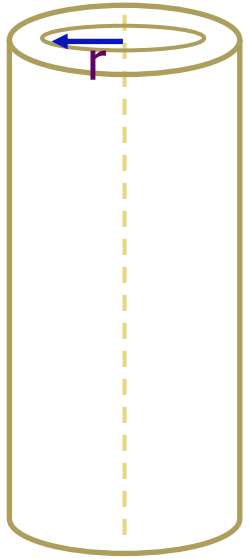
The limits for the stored energy density

SC properties & Magnet Geometry limit the stored energy density "e"

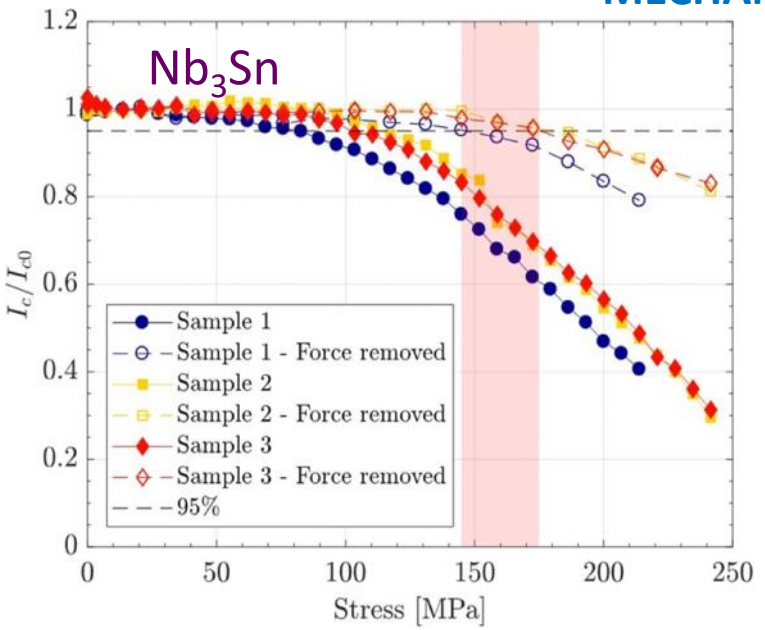
For an infinitely long solenoid or for a slender toroid (R>>r), the energy density "e" in Joules per Kg of superconductor, has two limits:

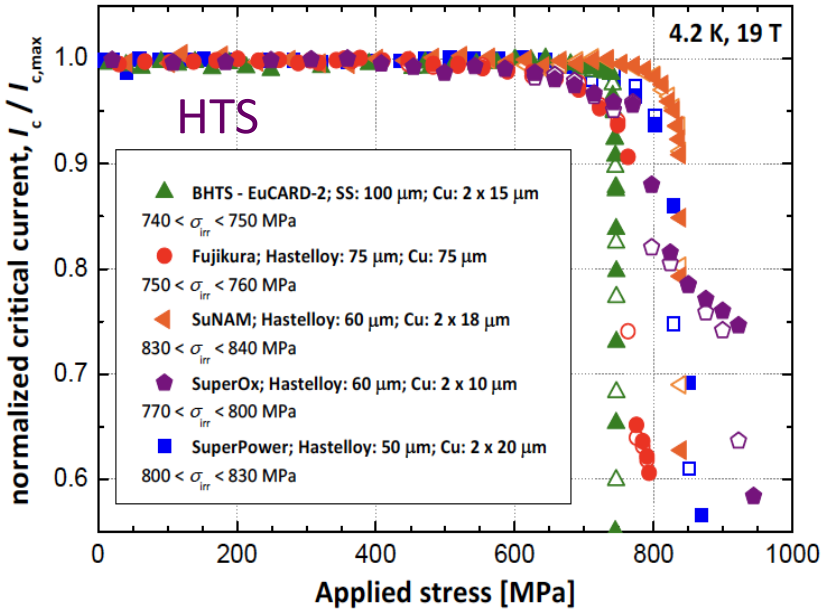
* MECHANICAL $e = K_m \cdot \sigma$ (σ=Max allowable stress)
* ELECTRICAL $e = K_e \cdot (B \cdot J)$



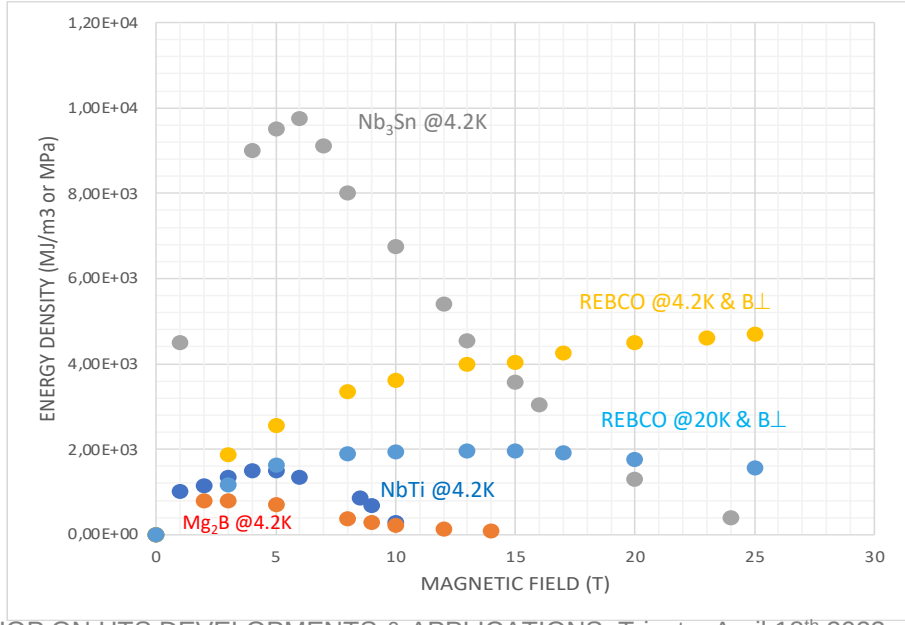


MECHANICAL LIMIT

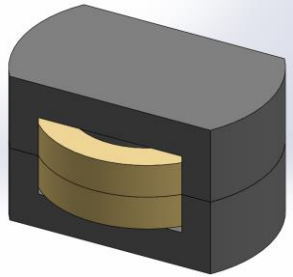




ELECTRICAL LIMIT

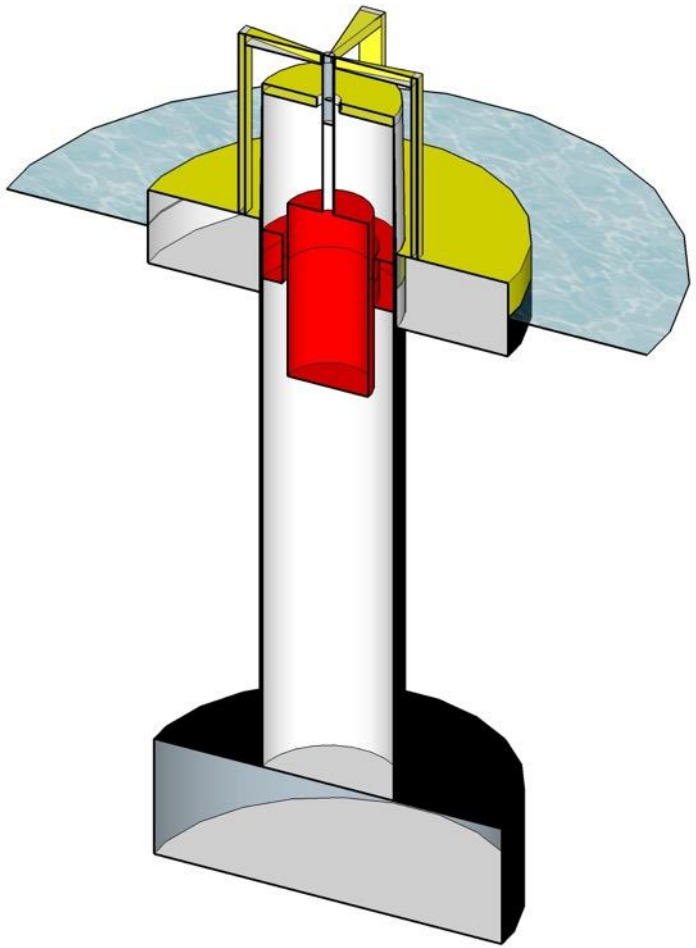


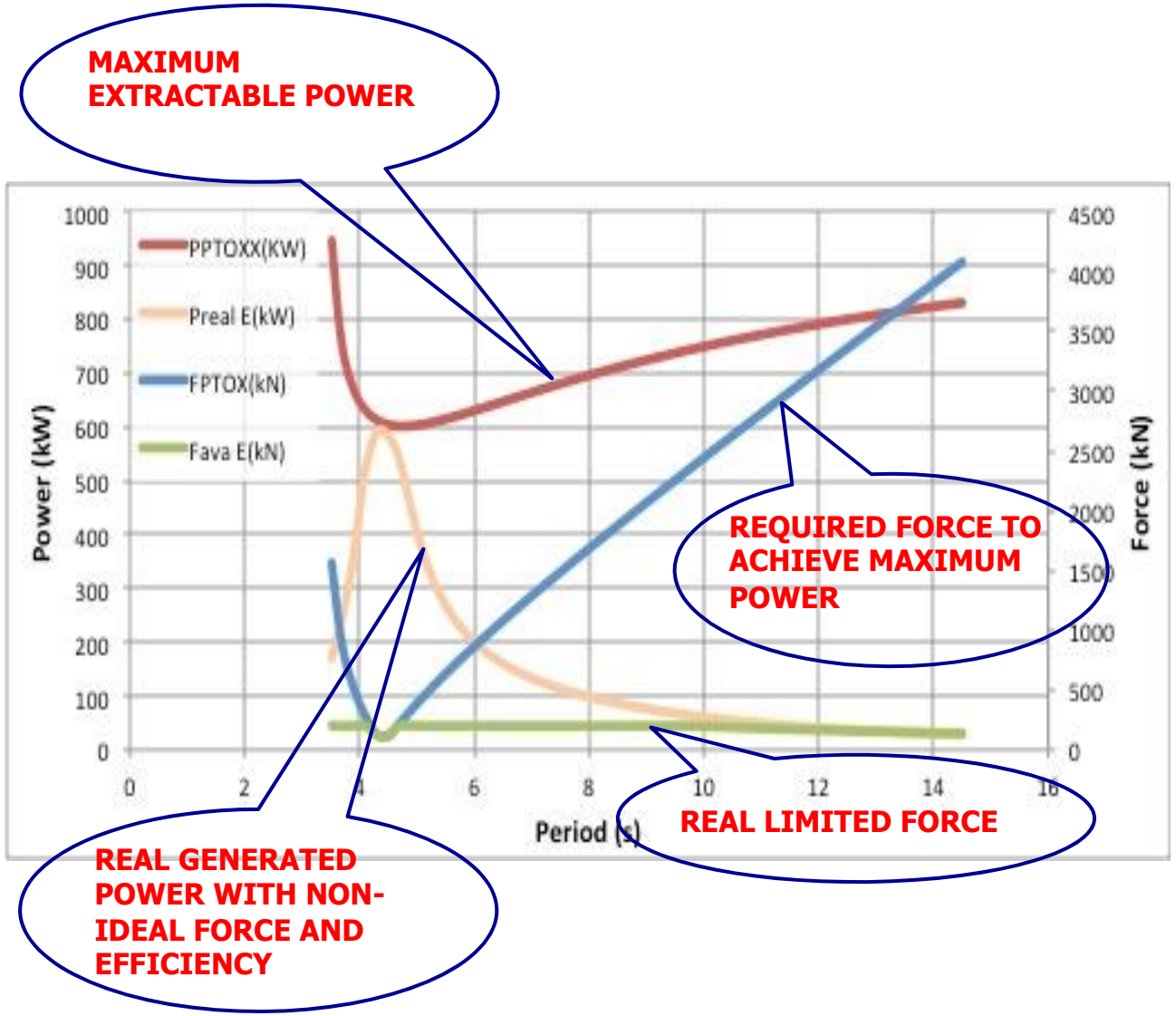
Magnet Configuration & SMES Operation

MAGNET CONFIGURATION			SMES OPERATION	
	Energy	100 kJ	Weight Constrains	According to the ship
	Power	100 KW	Volume Constrains	According to the ship
	Voltage	500 V	Max. Acceleration	0.4g Vert. 0,25 g Hor.
	Op. Temperature	TBD (10K-60K)	Max. Inclination	+- 45º during 12 s
	Conductor	REBCO Tape	Vibration	UN. DOT 38.3
		BiSCCO 2223 Tape	Shock	UN DOT 38.3 T4
		MgB_2 ?	Humidity	100% RH
	Magnet Topology	TOROID	Stray Field	< 0.5 mT
		IRON-SCREENED SOLENOID		
	Pancake Configuration	Layer jump vs 2 soldered tapes		
		Former (Y/N)		
		Connections		
		Mechanical Structure		

Development of a Linear Superconducting Power Take-Off SMES for Wave Energy Conversion

How does a Wave Energy Converter works?





It is clearly necessary to use high-force and high-efficiency PTOs to improve the capture capacity in real seas.

The SEA TITAN Project

Surging Energy Absorption Through Increasing Thrust And efficieNcy

GOALS:

- Developing a new PTO based on a Linear SRM

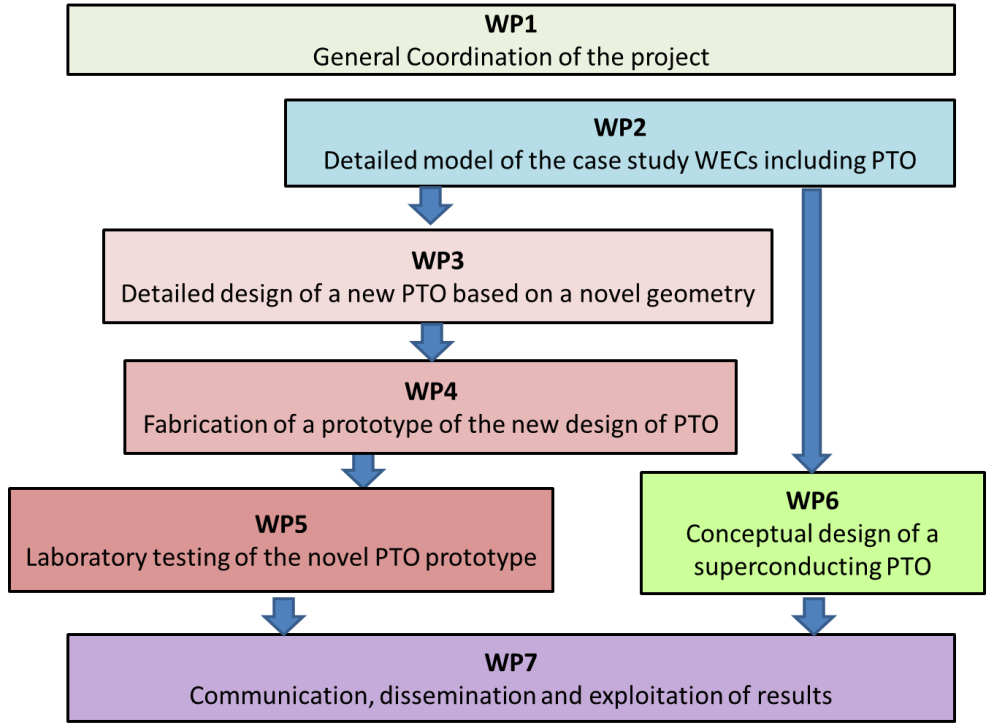
- Force Density x 2
- IPCR x2
- Increasing the FtWE up to 80%
- Reducing Capex/kW down to 25%
- Reducing LCoE in about 30%

- Modular & Cross Cutting up to 500 kN & 3m/s

- 3ª Generation based on a Superconducting PTO

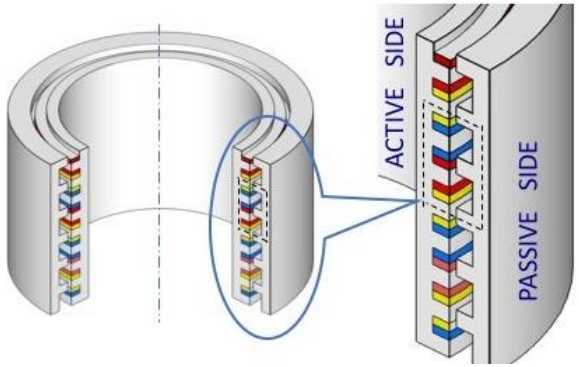
	Participant Organization name	Type	Country
1 (C)	Wedge Global S.L.	WEC Developer	Spain
2	CIEMAT	Pubilc R&D Center	Spain
3	WavEC - Offshore Renewables	R&D Center	Portugal
4	CorPower Ocean	WEC Developer	Sweden
5	Centipod LTD	WEC Developer	UK
6	Hydrocap Energy SAS	WEC Developer	France
7	OCEM Energy Technology 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

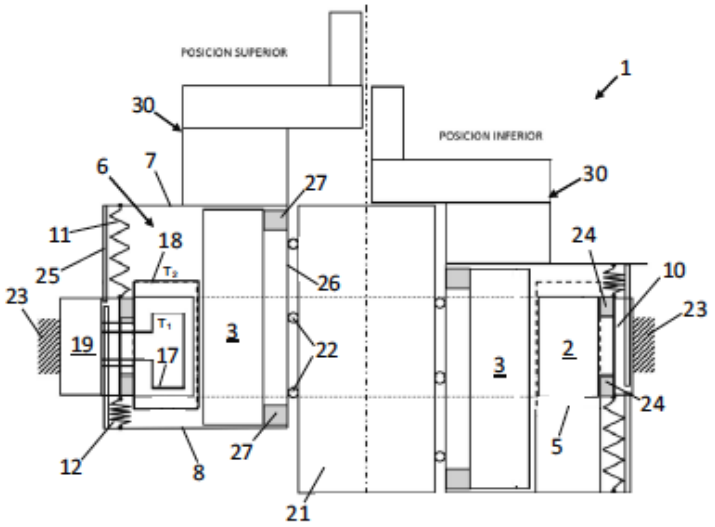
TYPE OF ACTION: RESEARCH & INNOVATION ACTION (RIA)



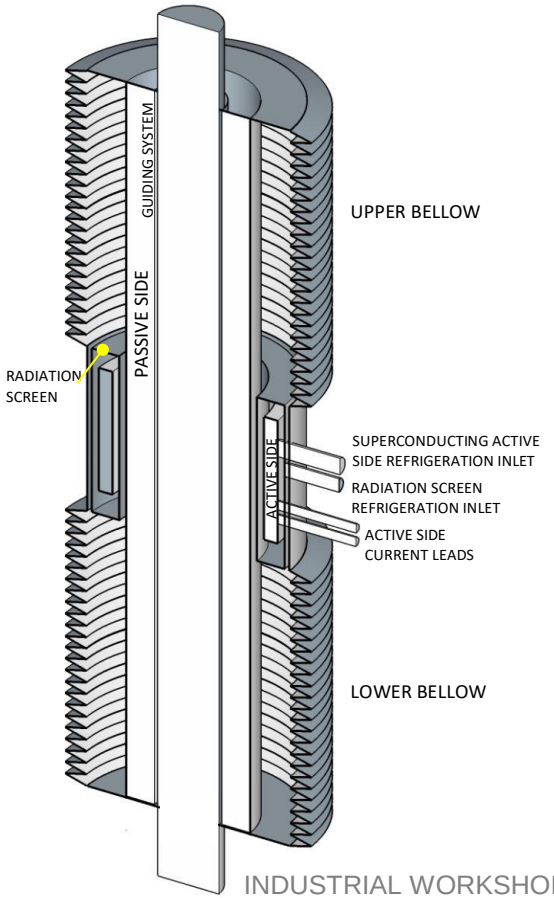
The Superconducting version of the Switched Reluctance Machine

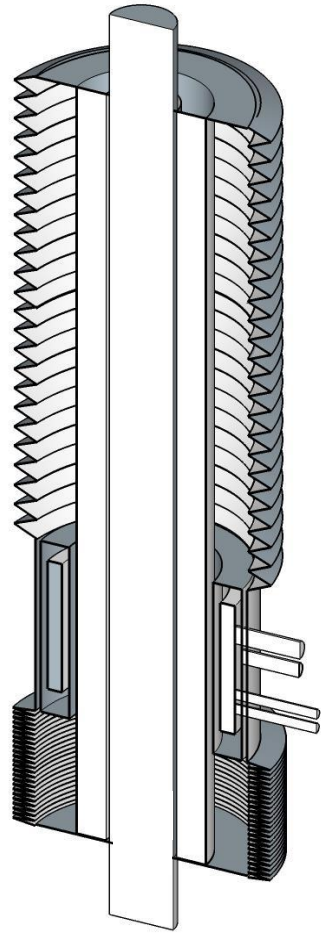
SeaTitan

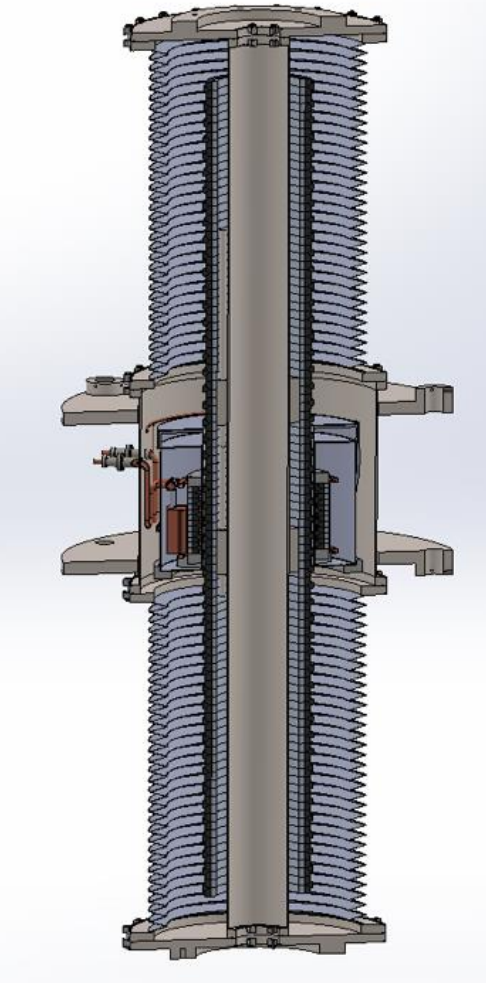




Based on a modified version of the 3rd configuration and on a cylindrical SRM, a new extremely compact concept was designed, analysed and patented. It is based on the idea of a deformable cryostat.







The SEA TITAN Project analysed the use of MgB2 as SC material, presenting many advantages. Nevertheless HTS superconductors, can also represent a very attractive option.

Summary

> CIEMAT has a long track record in applications of superconductivity. Most of the developments have been based on NbTi technology but recently we have a growing interest for exploring HTS technology.

> In this regard, and apart from magnets for Particle Accelerators, CIEMAT has started to investigate the HTS technology for energy applications, since energy is one of the core activities of the Laboratory.

> The first application is Superconducting Magnetic Energy Storage (SMES) with an initial application to waterborne transport. Nevertheless there are also other applications for SMES, particularly in systems requiring very fast response and very high number of charging/discharging cycles like laboratories, testing facilities, industry, etc.

> The second one is Wave Energy Conversion based on Superconducting Reciprocating PTOs. In spite the complexity of superconductivity for marine applications, the extremely high force than they can produce, makes attractive to explore this application which can also be translated to other sectors where High-Force reciprocating machines may be used.