Boosting Accelerator-SMES for Enhancing their Energy-consumption Efficiency

PARTNERS

CIEMAT (Lead Organization and IFast Member, *R&D Institute*)
CYCLOMED Technologies (Industrial and iFast Member, *Start-up company*)
ANTEC Magnets (Industrial Partner, *SME company*)

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MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
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Introduction: The Problem

BASE3

A ROUND-TRIP PROBLEM

1) The pulsed operation of some accelerators components (cycled magnets, special power supplies, etc) may have and impact on the grid stability inducing voltage drops or frequency fluctuations.

2) A lack of quality of the power grid like voltage drops & sags or frequency excursions may affect the operation of the Accelerator.

THE GENERAL SOLUTION: USING AN ENERGY STORAGE SYSTEM AS A POWER FILTER

The solution to the above mentioned problem is to use a fast energy storage system which will act as a filter to smooth the power taken from the grid. Eventually it will also act as an Uninterruptible Power Supply.

Device	Characteristics	Results – Real installations (examples) Facility (energy/power)
KESS	> 90% Efficiency > Fast response > Infinite Nº of Cycles > Maintenance Req. COMMERCIAL	• Fusion JT-60 (1300 MJ) • Accelerator J-PARC (original design) (51 MVA)
ESS Super-Caps	> 95% Efficiency > Fast response > Degradation > Repetitive life (~100.000) MEDIUM-HIGH TRL	• Accelerators: BNL-AGS; CERN-PS (12 MJ)
SMES	> 95% Efficiency > Fast response > Infinite Nº of Cycles > Maintenance Req. > AC Losses limitation LOW TRL (HTS)	• Accelerator BNL NSLS (2.4 MJ) • Accelerator J-PARC (enhanced design) (90MVA)

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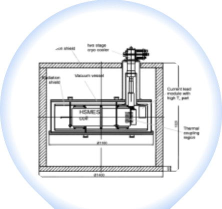
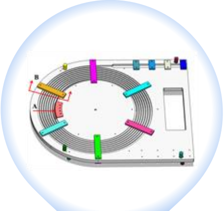
Our Proposal (I): Concept & Background

A modular SMES based on HTS and a He gas cooling system to guarantee an optimum refrigeration to the magnet

General SMES Pros	Specific BASE3 SMES Pros	SMES Cons
* No moving parts * Fast response time * High Power Density * Infinite Charge/Discharge cycles * Low Environmental Impact	* Modularity allowing to be scaled to different electrical requirements * Refrigeration system aimed at efficiently evacuating the heat produced by AC losses	* Low energy density * Presently, high CAPEX * Dependence of HTS wire development * Requirements of technically advanced operation personnel



POSEIDON
POwer StoragE In D OceaN

1984
SMES based on **NbTi** installed at the Tacoma Substation
10 MW, 30 MJ.

1997
CIEMAT & ANTEC collaborated in the AMAS 500 SMES for improving grid power quality
500 kVA, 1 MJ,

1999
Toroidal SMES, based on **NbTi,** for grid stabilization
1 MW, 3.6 MJ

2003
HTS SMES UPS system
20 kVA, 150 kJ

2006
SMES installed at the Electra Synchrotron Light facility as protecting device
1.2 MW, 2.6 MJ

2008
SMES, based on **Bi2212** for a power pulse source.
814 kJ, 315 A

2009
SMES based on **YBCO** wire for 100 MVA/2 GJ class load fluctuation compensating
100 MVA, 2.4 GJ

2022
YBCO tape based SMES for fluctuation suppression and energy compensation of the power system of a particle accelerator
1MJ

2022
H2020 Project granted to a consortium in which CIEMAT, CYCLOMED & ANTEC are included to analyse maritime applications of SMES & other Energy Storage Systems

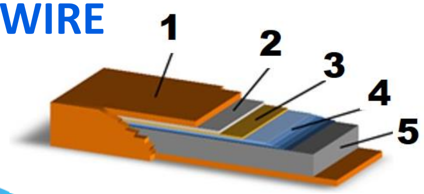
Our Proposal (II): The Preferable Choices

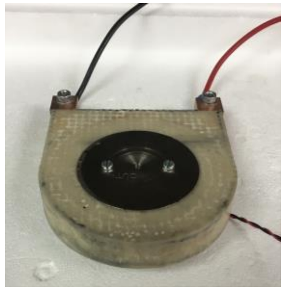
BASE3

	Type	Description	Advantages	Disadvantages
Material	Conventional HTS tape	REBCO tapes as a first choice. BiSCCO 2212 and BiSCCO 2223 will also be considered.	High critical temperature Less power required by the refrigeration system. Easier to remove AC losses.	Currently expensive. High AC losses which must be reduced.
Topology	MODULAR TOROIDAL	Toroidal arrangement of individual double-pancake solenoids . Solenoids made from double-pancake coils will also be considered.	Very low leakage flux. Easy to assemble from individual magnets easy to fabricate. Easy scalability and adaptation to different applications (modularity).	Lower magnetic energy density (J/Kg).
Refrigeration	CSS	Forced-flow configuration with the Cryogenic Supply System, where helium gas is circulated through the magnet and cooled down with a cryocooler.	Released heat is extracted very close to where it is produced (the wire) since the gas is circulated through the magnet and not removed from conduction.	More complex system than other solutions like conduction cooled devices.

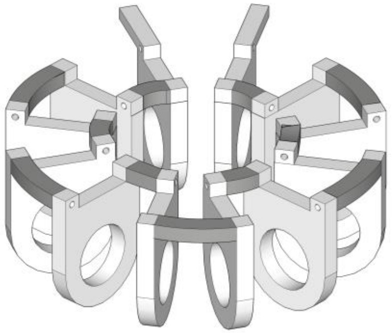
MATERIAL:
1. CU stabilisation (opt.)
2. Ag cao layer
3. REBCO layer
4. Buffer layer stack
5. Substrate

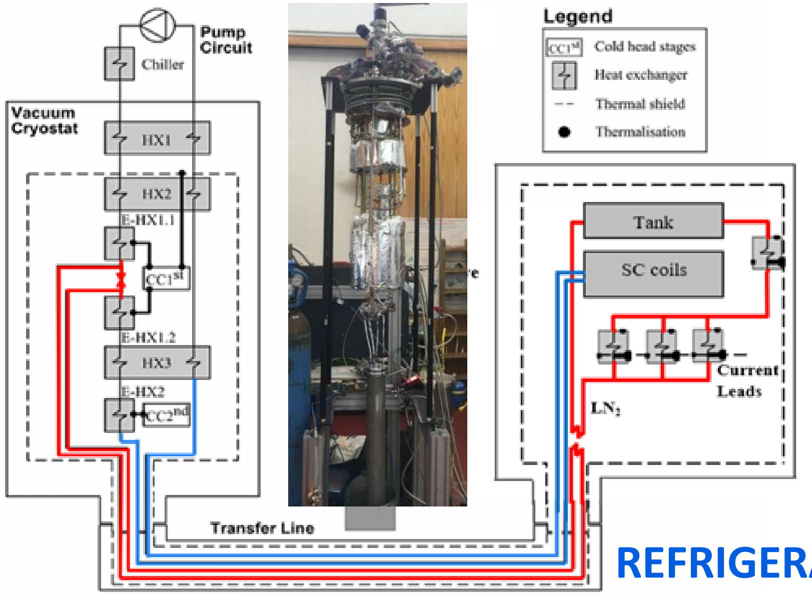
WIRE





ARRANGEMENT





REFRIGERATION

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Project Phases

TRL=3

TRL=4

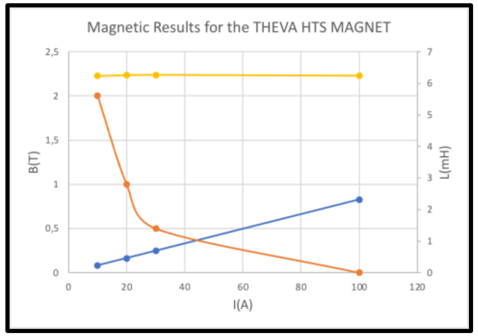
Design, Modelling & simulation

Manufacturing

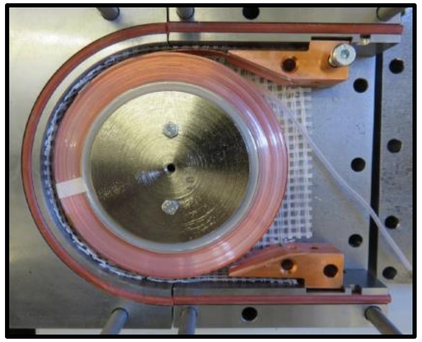
Validation & Testing

Business Plan & Dissemination

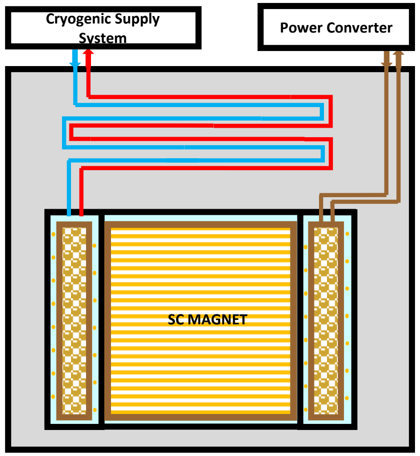
Design of the magnet and the cryostat as well as the adaptation of the CSS. The system will be modelled and simulated, especially for calculation of AC losses



The magnet will be made from a commercial HTS coil. The CSS will be adapted from an existing unit and the cryostat will be done ad hoc



Static & Dynamic tests will be performed. The first to characterise the magnet critical current vs temperature and the second to evaluate AC losses when ramping the magnet.



The project includes a specific work package (WP7) about business development in order to create new market opportunities and benefits to society, disseminate and exploit the project results, including management of IPR.

Reminders:

TRL3: *Critical Function, i.e., Proof of Concept Established. Applied research continues and early stage development begins. Includes studies and initial laboratory measurements to validate analytical predictions of separate elements of the technology. Examples include research on materials, components, or processes that are not yet integrated.*

TRL4: *Laboratory Testing/Validation of Alpha Prototype Component/Process. Design, development and lab testing of technological components are performed. Results provide evidence that applicable component/process performance targets may be attainable based on projected or modelled systems.*

Work Plan

Work Packages and Tasks		Lead	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			Months														
			P1		(50% payment)							P2		(50% payment)			
WP1	**PROJECT MANAGEMENT & COORDINATION**	**CYCLOMED**															
T1.1	General project management. Coordination and Communication	CYCLOMED						M1			M2				M3		
T1.2	Quality assurance and risk management	CYCLOMED															
T1.3	Data management	CYCLOMED						D1						D2			D3
WP2	**PROTOTYPE MODELING & CALCULATION**	**CIEMAT**															
T2.1	Overall system definition & specifications	CIEMAT															
T2.2	Subsystem definition & specifications	CYCLOMED															
T2.3	Model preparation for computing a.c. losses	CIEMAT															
WP3	**HTS-SMES DEVELOPMENT – CRYO-SYSTEMS**	**CYCLOMED**															
T3.1	Adaptation of the present CSS	CYCLOMED															
T3.2	Design & Fabrication of a magnet cryostat	ANTEC															
WP4	**HTS-SMES PROTOTYPE DEVELOPMENT - MAGNET**	**ANTEC**															
T4.1	Design & Fabrication of a SMES magnet	ANTEC															
WP5	**HTS-SMES PROTOTYPE DEVELOPMENT - POWER SUPPLY**	**CIEMAT**															
T5.1	Power Converter design and fabrication	CIEMAT															
WP6	**MODEL TESTING, VALIDATION & PROJECTION**	**CIEMAT**															
T6.1	Prototype integration & static testing	CIEMAT															
T6.2	Dynamic testing and thermal balance	CYCLOMED															
T6.3	Case study for Accelerator application	CYCLOMED															
WP7	**BUSINESS DEVELOPMENT: BUSINESS MODEL VALIDATION, IMPACT & OUTREACH**	**CYCLOMED**															
T.7.1	Plan for the dissemination and exploitation including communication activities	CIEMAT															
T.7.2	Dissemination, Communication, Exploitation activities. Business plan	CYCLOMED															
MS#	**M: Milestone, D: Deliverable**		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Deliverables:

- **D1** System Design Report (M7)
- **D2** SMES System: D2.1 Magnet / D2.2 Cryostat / D2.3 CSS
- **D3** Laboratory Tests Results Report

Milestones:

- **M1** System Designed
- **M2** Magnet Fabricated in Its Cryostat
- **M3** Experimental facility ready Incl. Cooling System & Power Supply

Consortium Background:

CIEMAT:
- SC Laboratory
- Manufacturing of SC Accelerator
- Magnets. - Power Converters.

CYCLOMED:
- Cryosystem
- SC Accelerators Magnets

ANTEC:
- SC & Resistive Magnets

Resources and budget

CIEMAT *is a public research institute depending on the Ministry of Science and Innovation. The Technology Department is one of the five Departments in which CIEMAT is organized and it is where the Electrical Engineering Division belongs. The division has more than 30 years of experience in superconducting magnets, cryogenics and power electronics*

CYCLOMED Technologies *is a Spanish company specialized in superconductivity and cryogenics. Founded in 2019 for the development and commercial exploitation of a superconducting particle accelerator aimed at radioisotope production*

ANTEC Magnets *designs and manufactures state-of-the-art magnetic systems and components for all types of applications. It is specialized in the manufacture of electromagnets (resistive and superconducting) and permanent magnets special configurations (Halbach etc.).*

Team and organizational expertise fully dedicated to the project

CIEMAT: Electric Eng. Division (Accelerator Unit & Power Systems): 1,5 FTE (Full-time equivalent)

CMT: 2 FTE

Industry participation and involvement

ANTEC : 1 FTE

Budget and resources provided by the consortium and IIF

	Personnel	Goods & Services	Travels	Total Project	Funding	Subsidy ratio
CIEMAT	60.000 €	38.000 €	2.000 €	100.000 €	50.000 €	50%
CYCLOMED	88.000 €	20.500 €	2.500 €	111.000 €	100.000 €	90%
ANTEC	37.500 €	22.500 €	2.500 €	62.500 €	50.000 €	80%
			Total	**273.500 €**	**200.000 €**	73%

Budget breakdown

PARTNER	CIEMAT	CYCLOMED	ANTEC
PM Rate	**2667**	**2933**	**2500**
Total PMs	**22,50**	**30,00**	**15,00**
A. Personnel costs	**60.000 €**	**88.000 €**	**37.500 €**
B. Subcontracting	- €	- €	- €
Travel and subsistence	**2.000 €**	**2.500 €**	**2.500 €**
Travel for Physical Project Meetings	2.000 €	2.500 €	2.500 €
Equipment and Consumables	**38.000 €**	**20.500 €**	**22.500 €**
Equipment for Living Labs, trials, pilots			
Consumables for Living Labs, trials, pilots	38.000 €	20.500 €	22.500 €

Risk Analysis

Description of risk	Impact & Likelihood	Proposed risk-mitigation measures
* Partner fails to perform committed tasks	I: High L: Low	> The consortium is relatively redundant. One partner can undertake the tasks of the others > Externalization of tasks
* Conflicts or disagreements in the consortium	I: High L: Low	> Establishing a management structure and a clear assignment of responsibilities
* Delays in critical path deliverables * Non-compliance with specifications	I: High L: Low	> A back-up provider will be always consider (especially for HTS coils) > A small safety margin has been considered for integration in the project schedulle
* System is unable to achieve nominal temperature	I: Low L: Medium	> Coils will be designed to work with a safe temperature margin to allow extracting more power with the refrigerator working at higher temperatures
* AC losses above expected	I: Medium L: High	> Increasing working temperature to increase power extraction capacity (see previous point) > A.C Losses Model reconfiguration & analysis of other future wire alternatives.

Selected Applications and Impact

TYPE	APPLICATION	DESCRIPTION	IMPACT
ACCELERATORS & SCIENTIFIC FACILITIES	**Cycled Magnet** Power Management	Power recovery of cycled magnets	> Reduction of size and cost of electrical protection systems > Reduction of the electricity bill > More energy efficient accelerators (less reactive power consumption)
	Powering of **Pulsed Power Supplies** for Accelerator Components	Powering of modulators for klystrons	
	Grid **Power Filters for Pulsed Facilities**	Reduction of power peaks to the grid for experimental facilities running in pulsed mode (Fusion, Ultra High Field pulsed magnets, Hyperloop,…)	
	UPS for Grid Disturbances Load Protection	Fast protection of high power loads and safe shutdown of the accelerator	> More reliable accelerators with less impact of shutdowns
SOCIAL APPLICATIONS	**UPS** for Grid Disturbances **Critical Load** Protection	Fast protection of high power loads in delicate fabrication processes	> Reduction of costs due to unexpected grid disturbances
	Fast Cycling Load Levelling	Short period peak shaving. Part of load levelling hybrid systems in combination with batteries or fuel cells and microgrids or for renewable energies applications.	> More efficient grids with more penetration of renewables in the overall context of energy storage
	Hybrid Vessels	Peak support to Electric & Hybrid vessel (ships) for manouvring and harbour operation	> Substitution of fossil fuel based vessel with hybrid o full electric sustainable ships

Business Plan

	DESCRIPTION
Hadron Therapy	Sustainable medical accelerators ○ Advanced medical equipment to treat cancer. Local control of tumors and lower toxicity to healthy tissue ○ Requires accelerators with large load consumptions.
Business model	Market & Revenue: ○ 5 P-HT centers in 2009, 15 in 2017, and 33 in 2021 just in Europe with expected **double digit CAGR for the next decade for the HT sector** worldwide. ○ Sector growth, and need for sustainability **will drive demand for Energy Storage** solutions in the accelerator area, in which our proposed solution will thrive due to its **key competitive advantages: high nº of duty cycles, and low specific cost per kW.** ○ Proposed direct sales business model since partners has established connections in the medical accelerator area
Use case	**CNAO:** a multi-modal European clinical center (protons and carbon ions to 250 MeV and 4800 MeV respectively) **Support letter CNAO director.* **Power consumption:** Est. consumption of 100 kW for the dipole magnets with a deceleration period of 0.5s in pulsed mode. **Advantages**: Incorporating a 100 kW SMES **(Est. CAPEX: 80-100k€).** ○ Energy savings: Energy can be recovered in the deceleration phase / *90% efficiency 45kJ could de recuperated per cycle, which with a 200€/MWh electricity cost yields 0.25c€ savings per cycle. Est. nº of cycles per year are about **3M**, thus **7.5k€ savings per year**. Pay-back of 11 years.* ○ Grid stability: SMES can **provide dynamic stability** during voltage sags or act as a UPS to assure correct the operation of the facility.
IPR Status	○ Current status: There is no existing patent to protect the proposed solution and results on the CSS have been published ○ IP Strategy: The consortium will adopt a mixed IP strategy, combining industrial secret with dedicated patents on specific subsystems

(*) Selected among *several other possible options*

1 doi: 10.1016/J.APENERGY.2014.09.081.

The commercialization

BASE3

Product development phases	Concept & Market research	Prototype testing	Product development	Go To Market
Funding path to market	IIF	EU Grants	EU Grants - EIC Accelerator	Private Funding

TRL 3 TRL 4 TRL6 TRL8

Jan. 2023

IFAST Innovation Fund

Test & Validate the technology. Confirm market interest.

March-Sept 2024

> HORIZON-INFRA-2024-TECH-01-02 (*)

> EIC Pathfinder

Develop full prototype (TRL 6/7). Define partners, in the accelerator sector, to test the technology.

2nd Sem. 2026

EIC Accelerator

Test product in real conditions. Open new collaborations: medical accelerators.

Year 2028/2029

Go to Market

Expand to new sectors, find new partners (Energy, aerospace or military).

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Back up Slide

(*) Preliminary information for the HORIZON-INFRA-2024-TECH-01-02: New technologies and solutions for reducing the environmental and climate footprint of RIs

Scope: The aim of this topic is to **deliver innovative technologies and solutions which reduce the environmental and climate footprint of RIs** through the full life cycle of research infrastructures. Proposals should **identify common methodologies, among the concerned RIs**, to assess environmental impact and strategies to reduce it.

Proposals should address the following aspects, as relevant:

- new technologies and solutions for research infrastructures enabling **transformative resource efficiency (e.g. energy consumption) and reduction of environmental (including climate-related) impacts**, including, when relevant, more sustainable and efficient ways of collecting, processing and providing access to data;
- **validation and prototyping**;
- training of RI staff for the operation and use of the new solutions;
- **action plans to deploy the new developments at wider scale and ensure their sustainability**;
- measures to ensure an environmentally effective integration of the solutions in the local contexts;
- **societal engagement to foster acceptance of the solutions** in the local and regional communities.

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