Tecnologias Disruptivas Aplicadas em Sistemas Elétricos de Energia

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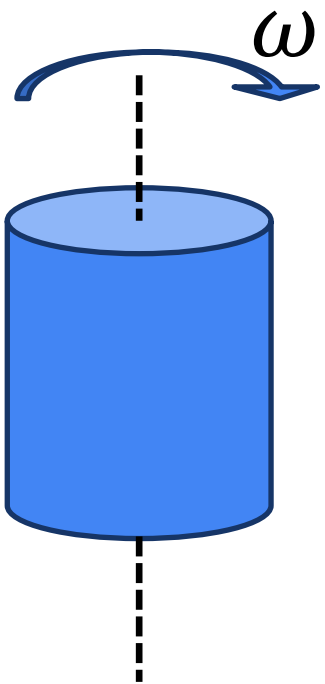
Juiz de Fora, 30 de Abril de 2025

Flywheel Energy Storage System (FESS)



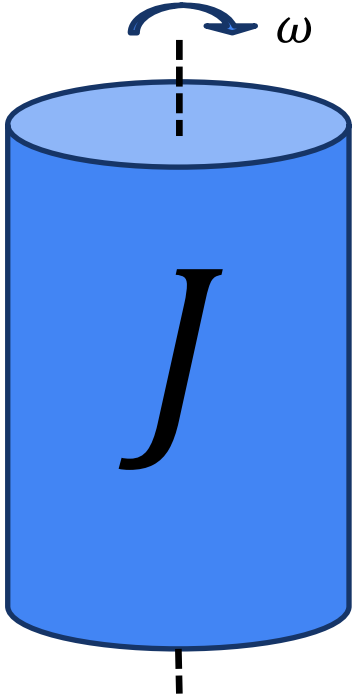
Energy stored in a flywheel:

$$E = \frac{1}{2} J \omega^2$$

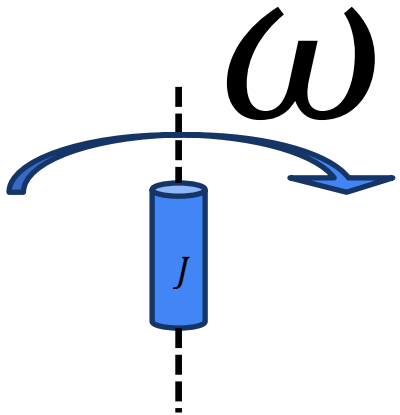
J – Moment of inertia

ω – Angular speed

1 – Low-speed Flywheels



2 – High-speed Flywheels



Kinds of FESS

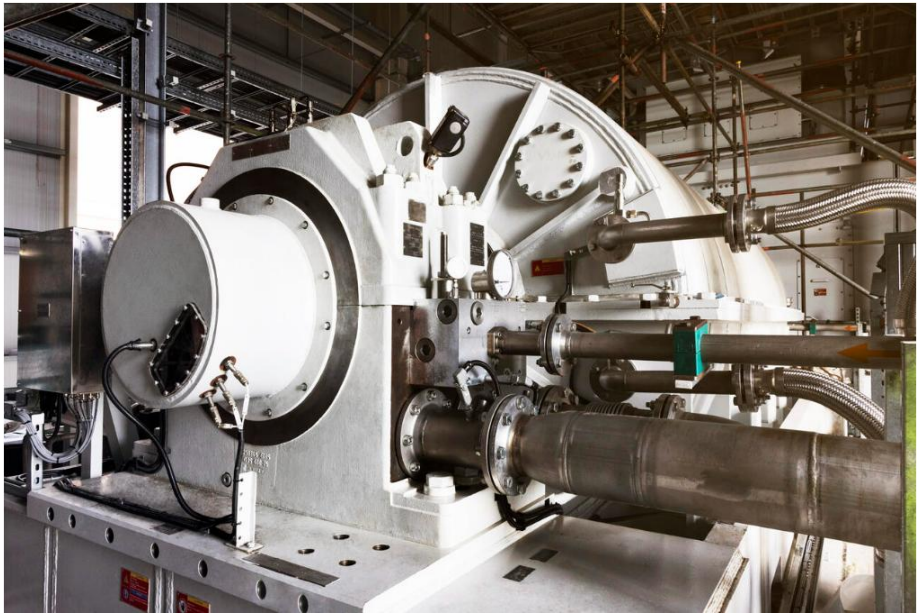
Low-Speed x High-Speed FESS

Feature	Low-Speed FESS	High-Speed FESS
Energy Density	Low	High
Size and Weight	Large and Heavy	Small and Light
Complexity (Vacuum, Bearings, Materials, etc)	Simpler	Complex
Energy Decay	High	Low
Response time	Slower	Very Fast
RTE (Round Trip Efficiency)	Moderate (~70-85%)	High (~85-95%)
Energy Retention	Short (minutes)	Long (hours)

Major FESS Projects Worldwide on Grid

SIEMENS and Electricity Supply Board FESS @ Moneypoint, Ireland

- **Power:** 400 MVA
- **Energy Capacity:** 160 MWh
- **Units:** 1 synchronous condenser
- **Application:** Grid stability (provides inertia, frequency regulation, and voltage control to a 1,500 MW offshore wind farm)
- **Rotor weight:** 130 tons
- **Rotor speed:** 3,000 rpm
- **Discharge Time:** Not specified
- **Start of Operation:** 2024
- **Notes:** The world's largest flywheel in a single device
- **Total Investment:** US$ 50 Million



Source: https://www.siemens-energy.com/global/en/home/stories/irelands-great-grid-stabilizer.html

Major FESS Projects Worldwide on Grid

Dinglun Flywheel Energy Storage Power Station – Changzhi, China

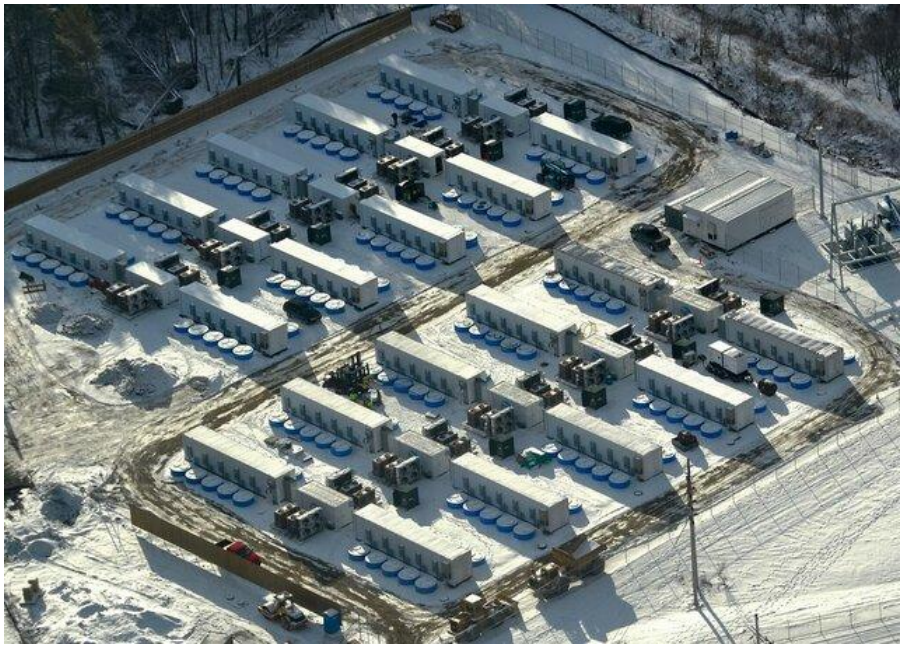
- **Power:** 30 MW
- **Energy Capacity:** Not specified.
- **Units:** 120 high-speed flywheels (250 kW/unit)
- **Application:** Grid frequency regulation
- **Discharge Time:** Not specified
- **Start of Operation:** 2024
- **Notes:** The largest flywheel energy storage system in the world as of 2024
- **Total Investment:** US$ 48.1 Million

Source: https://www.energy-storage.news/worlds-largest-30mw-flywheel-energy-storage-project-connects-to-grid-in-china/

Major FESS Projects Worldwide on Grid

Beacon Power – Stephentown, Nova York, EUA

- **Power:** 20 MW
- **Energy Capacity:** 5 MWh
- **Discharge Time:** 15 minutes
- **Units:** 200 flywheels (per unit: 100 kW, 25 kWh)
- **Application:** Frequency regulation
- **Start of Operation:** 2011
- **Notes:** The first commercial FESS project in the U.S.
- **Total Investment:** US$ 69 Million.



Source:https://www.researchgate.net/publication/282283808_Electric_Energy_Storage_-_IEA_ECES26_Future_Energy_Storage_Demand/figures?lo=1

Major FESS Projects Worldwide on Grid

Minto Flywheel Facility – Ontario, Canada

- **Power:** 2 MW
- **Energy capacity:** 500 kWh
- **Discharge time:** 15 minutes
- **Units:** 10 flywheels (per unit: 200 kW, 50 kWh)
- **Application:** Frequency regulation
- **Commissioned:** 2014
- **Notes:** First flywheel system connected to the grid in Canada.
- **Total Investment:** Not Available.

Source: https://www.ieso.ca/en/Powering-Tomorrow/2021/Ontarios-first-hybrid-storage-facility-is-here

Source: https://nrstor.com/2019/11/21/2-mw-minto-flywheel-facility-market-impact-case-study-power-advisory/

Major FESS Projects Worldwide on Grid

WEB Aruba / Temporal Power – Oranjestad, Aruba

- **Power:** 5 MW.
- **Energy capacity:** 1 MWh.
- **Discharge time:** 12 minutes.
- **Units:** 20 flywheels (per unit 250 kW).
- **Application:** Renewables capacity firming and resiliency.
- **Project Announced:** 2015 (It is not clear if the project was already commissioned).
- **Total Investment:** Not Available.

Source: https://youtu.be/iGmAnoEtakM

Major FESS Projects Worldwide on Grid

Emerging Power – Subic, Philippines

- **Power:** 10 MW
- **Energy capacity:** 1 MWh.
- **Units:** Not available.
- **Application:** Frequency regulation and renewable energy smoothing
- **Technology provider:** Amber Kinetics (M32) every unit has 8kW and 32kWh.
- **Announced:** 2019
- **Notes:** Part of a 150 MW renewable energy complex.
- **Total Investment:** USD $200 Million (including the generation plant)

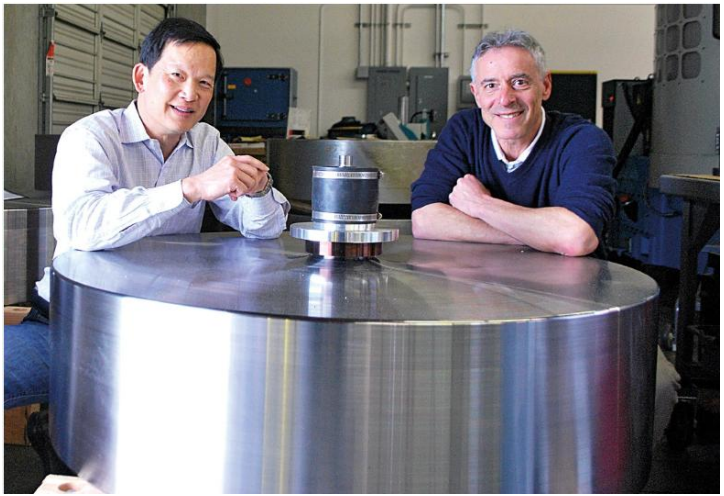
Source:https://amberkinetics.com/installation/utility-of-the-future/

Commercial FESS Units

Amber Kinetics - M32 (8kW,32kWh)

“The Amber Kinetics M32 (8kW,32kWh) is the first commercialized four-hour discharge duration Kinetic Energy Storage System (KESS) powered by advanced flywheel technology that stores 32 kWh of energy in a two-ton steel rotor.”

Source: https://www.amberkinetics.com/wp-content/uploads/2020/05/Amber-Kinetics-DataSheet.pdf



Source: https://www.nature.com/articles/545S13a

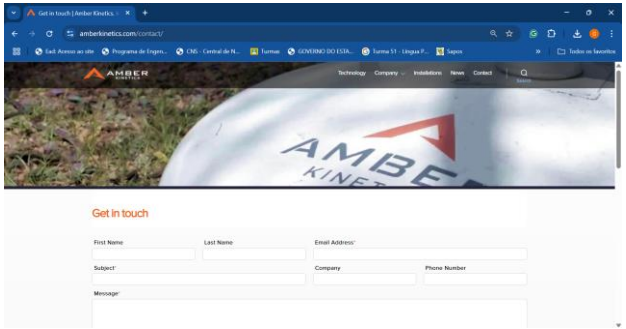
Source: https://www.amberkinetics.com/wp-content/uploads/2020/05/Amber-Kinetics-DataSheet.pdf

- > 86% round trip efficiency (DC)
- No daily cycling limitations, No degradation over time
- Operates in hot and cold environments (-20C to 50C)
- Fast response time (< 1 s)
- Lower O&M cost
- 30-year design life
- 10-year manufacturer warranty
- 100 W Power losses
- 2,3 tons rotor
- 9,000 rpm

Commercial FESS Units

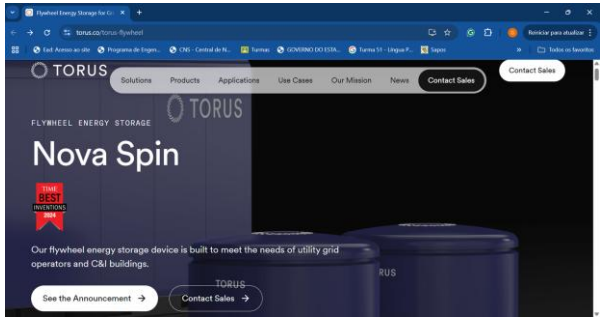
Amber Kinetics -

M32, USA



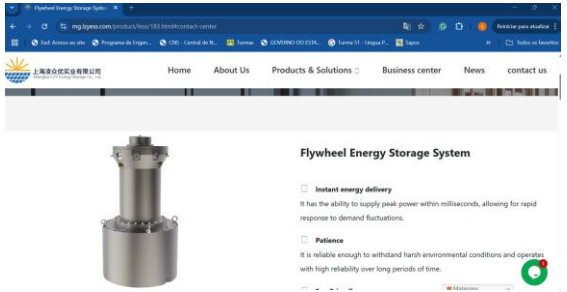
https://amberkinetics.com/contact/

Torus – Nova Spin, USA



https://www.torus.co/torus-flywheel

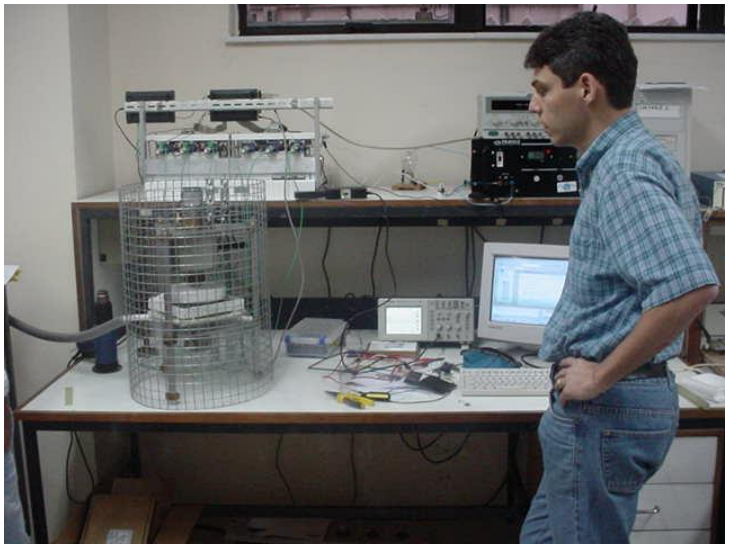
Shanghai LZY Energy Storage Co., China



https://mg.lzyess.com/product/fess/183.html#contact-center

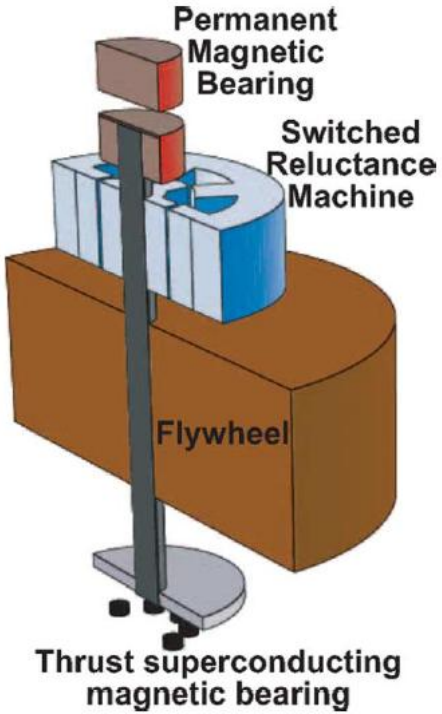
Previous research from the group

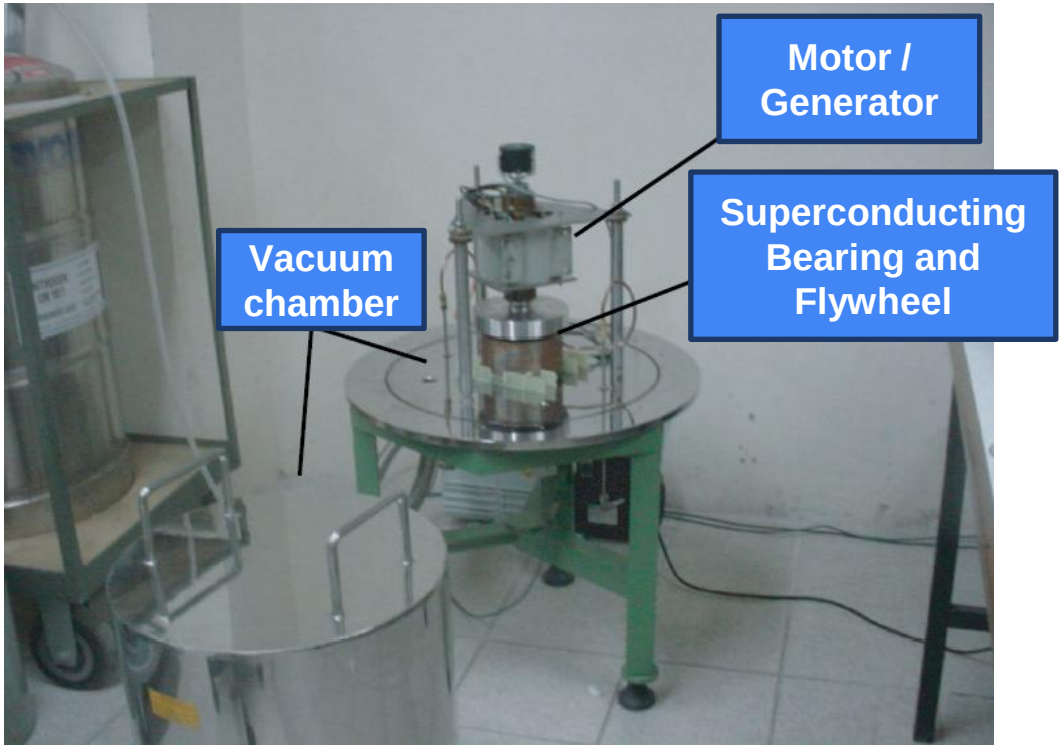
Flywheel Prototype (2004 – R&D Light/UFRJ)



Previous research from the group

Flywheel Prototype (UFRJ 2007)

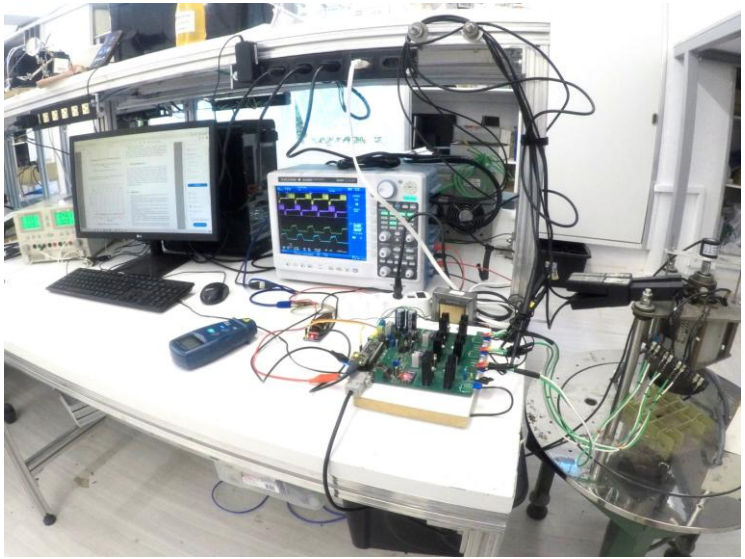


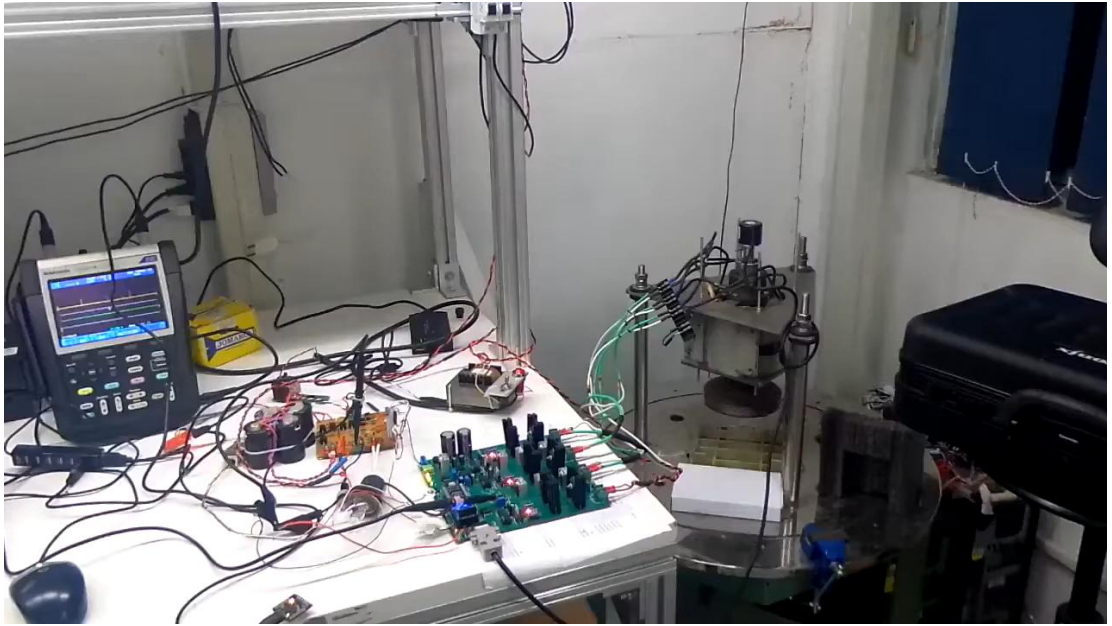


Previous research from the group

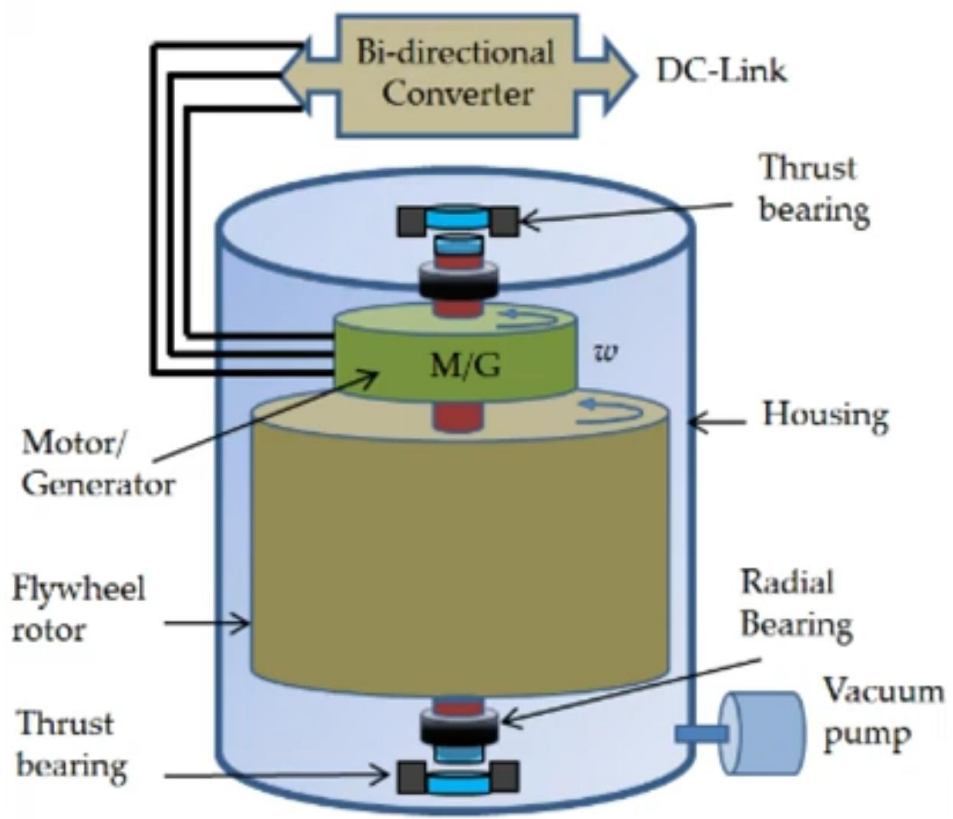
Flywheel Prototype (UFF 2018-2022)

2018 - M.Sc. Gustavo Luiz Ferreira: Ensaios em uma máquna de relutância variável aplicada ao Armazenamento de energia
2022 – M.Sc. Thiago da Silva Bumpus: Operação e controle de uma máquina de relutância variável para armazenadores cinéticos de energia



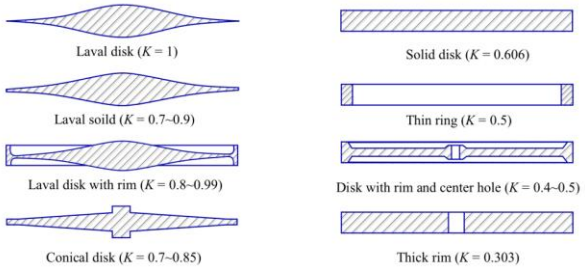


Main FESS Components



Points to be optimized for the Brazilian FESS development

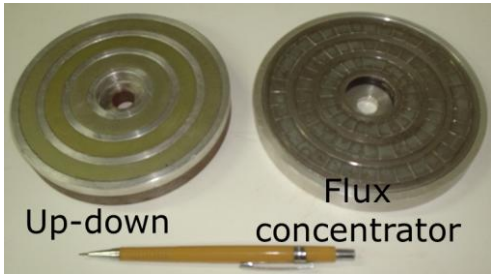
Flywheel Shape



$$e = K \times \sigma / \rho$$

where e is the energy storage density of the flywheel, in Wh/kg, K is the shape coefficient of the flywheel, ρ is the density of the material, in kg/m^3, and σ is the tensile strength of the material, in MPa.

Magnetic Bearings

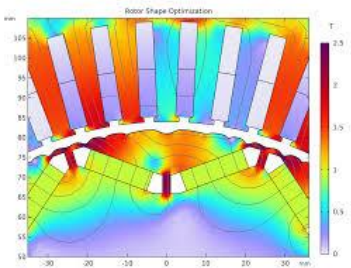


Vacuum Chamber

Flywheel Material

Materials	Energy Storage of Different Materials		
	σ/GPa	ρ/kg·m^{-3}	e/Wh·kg^{-1}
E glass fiber/resin	3.5	2540	231.9
S glass fiber/resin	4.8	2530	320.6
Kevlar	3.8	1450	441.1
Spectra fiber/resin	3.0	970	520.6
Carbon fiber T-1000/resin	10	1800	945.7
High-strength steel	2.7	7800	56.8
Aluminum alloy	0.6	2700	36.1

Motor/Generator



Power converter

Final Remarks

- There is an urgent global demand for commercially viable electrical energy storage solutions

- Flywheel technology has evolved significantly in recent years, and some manufacturers have developed commercial FESS

- The development of a Brazilian FESS is feasible but would require substantial R&D investment

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Obrigado!

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