Flywheel Mass Energy Storage with HTS Bearing – Development Status

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IRES I

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Any stressed un-buffered non-linear system is highly susceptible to collapse

Imre Gyuk, Program Manager, Energy Storage Research, DOE
Dynastore
UNIPEDE Statistics (1995)

Number of Outages p.a.

<table>
<thead>
<tr>
<th>Interruption time</th>
<th>0</th>
<th>0.5</th>
<th>1 s</th>
<th>3 s</th>
<th>20 s</th>
<th>&gt; 20 s</th>
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Voltage sag %

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power failures per Year in Europe:
- > 10 ms: 346
- > 100 ms: 209
- > 3 s: 10

In Germany:
55 failures per year, with
9.6 short time breaks < 100 ms,
0.4 long time breaks > 1 min
Liberalisation and reduced reserves in power grids will cause increasing number of power failures.

Increasing numbers of disperse and regenerative energy suppliers will affect the stability of the power grid.

Increasing numbers of computer controlled manufacturing processes leads to increasing sensitivity of customers against disturbances in the power grid.

In consequence necessity to use energy storage systems to maintain power quality.
A stable Grid with regenerative sources needs at least two types of energy storage:

- Fast responding (msec .. sec) storages for transient stability and power quality
- Slow responding systems (sec..min) for balancing the difference between actual demand and actual production
- In general the amount of stored energy corresponds with the response time (fast responding systems have usually small amounts of stored energy)
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**Characterisation of storage systems**

<table>
<thead>
<tr>
<th>Type of Energy</th>
<th>Electrical</th>
<th>Magnetical</th>
<th>Thermic</th>
<th>Potential</th>
<th>Kinetic</th>
<th>Chemical</th>
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<tbody>
<tr>
<td>discharge time</td>
<td>Capacitor</td>
<td>LTS-SMES</td>
<td>Hot water, hot steam, molten Salt, Solid body storage (Cowper storage, rock, concrete etc.)</td>
<td>Spring Storage$^{1)}$</td>
<td>Flywheel</td>
<td>$\text{H}_2$ tank+fuelcell, fossil fuel tank + thermal energy converter (ICE, Gas Turbine..) Chem. batteries (PB-, NiCd-, Li-Ion, VaRedoxFlow, NaS)</td>
</tr>
<tr>
<td>Short Sec. min</td>
<td>Supercapacitor</td>
<td>HTS-SMES</td>
<td>Compressed Air (CAES)</td>
<td>Compressed Air</td>
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<td>medium min hrs</td>
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<td>long hrs day</td>
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$^{1)}$ In practical use for brakes only
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Features of a flywheel storage

- High efficiency
- High power density
- Advantageous cumulated Energy consumption
- Small stand by losses
- High lifetime / Cycle Numbers
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Goals for a fast responding Flywheel energy storage system

- Flywheel energy storage with rated power $P = 2\, \text{MW}$
- Ride through time 20 sec
- Netto Energy content 11 kWh (Brutto : 14 kWh)
- Minimum „Stand By“ Losses

Applications
- Power quality and UPS
- Peak shaving
- Urban Traffic
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The dynastore consortium

Market leader
for large power supply systems

Materials
Research & Production
High temperature superconductors

Piller GmbH

Electrical engineering
Flywheel, Energy Converter, Inverter, HTSC-magnetic bearings

IMAB Institute for Electrical Machines, Drives and Traction, TU Braunschweig

Power semiconductors
eupec GmbH

Utilities
User

CFRP and production technology

DLR e.V., Braunschweig Institute for Structural Mechanics

Materials Research & Production

SuperConductors

Solvay GmbH

Institute for Structural Mechanics

CFRP and production technology

DLR e.V., Braunschweig Institute for Structural Mechanics

Solvay GmbH

SuperConductors

IPHT e.V., Jena

gGmbH, Göttingen

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Solvay GmbH
High Temperature Superconductor (HTSC) Flywheel Bearings
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Component structure of a Flywheel with active / HTSL bearings
HTSC bearings are specifically „soft bearings“, which should be operated above the critical speed.

The low Eigenfrequency yields high running smoothness.

Inherent damping is weak. External damping necessary.

Superconducting bearings show a progressive characteristic and linearisation at the point of operation by the gradient of the local hysteresis loop is possible.

The frequency dependence of the properties are linear up to high frequencies, but additional effects due to eddy currents may appear.
Inherent stability in radial and axial direction
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*Principles of activation*
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HTS Bearing with 500 kg load capacity for a 4 MVA HTS Generator

HTSC Bearing with movable sleeves for centric rotor position
Assessment of superconducting bearings for flywheels

- **Activation**
  Simple activation by vertical movement of the rotor into operation position under gravity

- **Safety**
  no crash possible if proper designed (No EMC problems, no sensor failure)
  Long thermal time constant when cooling fails

- **Losses**
  No stator losses, if smooth flux distribution is achieved
  no rotor losses except parasitic eddy current losses
  Energy consumption of the cryocooler increases the loss balance

**But**

- **Long cool down** time necessary
- **Actuators for Activation** of bearing necessary
- Long lifetime, low cost stirling-cryocoolers with sufficient power are under development but not yet available

- **For a continuous operating flywheel with high energy content HTSC bearings are preferable due to the safety aspects**
Design Principles of Flywheelsystems
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Mass loaded Flywheel with external Motor, $J_p/J_a < 1$

Flywheel for bus propulsion

$P = 150\ kW$, $n = 40,000\ min^{-1}$, $W = 2\ kWh$

University of Austin, Texas,
Dynastore
Features of mass loaded flywheel

- Shaft with bearings on small diameter,
- Active bearings with small gap and reduced losses
- Heavy construction with high amount of fiber material
- Low energy density
- \( J_p/J_a < 1 \)
- Requires bearings of high stiffness and damping
- Suitable for high rpm designs together with AMBs
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Stator, Rotor and cooling conductors assembly

Rimmed Flywheel

- CFRP Rim
- Hub with CFRP reinforcement
- HTS Bearing
- Coupling structure
- Stator of Motor/Generator
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Hub – rim construction with integrated machine and bearings

- **Compact in size** because machine and bearings are integrated into the rotor bore

- **Low weight**, main portion of energy is stored in the rim

- **Differences in elastic deformation** between hub and rim compensated by a patented novel radial elastic coupling structure providing structural Eigenfrequencies far away from the rotational frequency

- **Bearings with large active surface** possible

- **$J_p/J_a > 1.5$**

- **Suitable for high circumferential speeds** with SMBs
Examples of actual Flywheel Designs
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Powerbridge, Piller Power Systems, 4.6 kWh, 14 sec

Technische Daten:
- Stored energy: 16.5 MWs
- Rated power: 1650 kVA
- Speed: 1800 bis 3300 rpm
- Total weight: 6000 kg
- Rotorweight: 2900 kg
- No load losses: 10 kW
- Bearing regreasing: 6 months
- Bearing lifetime: 8 years

Features:
- Helium atmosphere
- Magnetic load control
- Redundant bearings
**Dynastore**

**VYCON / Calnetix, Ca. 125 kW, 12 sec, 0.4 kWh**

- **Motor/Generator**
  - High Speed Permanent Magnet
  - Minimum Stator and Rotor Loss for Low Parasitic Losses
  - Steel Sleeve for High Rotor Stiffness

- **Magnetic Bearings**
  - Low Cost Actuator and Sensor Configuration
  - Standard Calnetix Controller
  - Grease Lubricated Backup Bearings

- **Flywheel Rotor**
  - High Strength Steel Hub
  - High Factor of Safety on Burst

- **Housing**
  - Steel Housing
  - Simple Assembly Approach
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Boeing Phantom works, 100 kW, 4 kWh, 2.4 min

- Lift bearing
- Motor/Generator
- Hub
- HTSC bearing
- Composite Rotor
- Vacuum vessel with energy absorbing liner
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Experimental Flywheel assembly with vacuum container

11 kWh,
2 MW, 20sec
10000 rpm
Minimal standby losses
Response time 2 msec
Actual state of experimental setup
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Structure of redundant power and control electronics

Brake choppers

Flywheel with double machine

Rect. control
Control WR 2
Control WR 1

SPS

Grid failure

Customer

Grid
Dynastore

Inverter and control cabinet (4 MVA inverter)
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Vacuum vessel for the test setup
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Central mechanical hub structure

958 mm

Motor/Generator hub and water jacket

Bearing hubs
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Statorwinding of the SRM hub drive

Central Hub and water jacket
Dynastore

Application of the safety sleeve on the HTSL Bearing
Conclusion
The Dynastore Flywheel energy storage project aims at transient stability of power grids and urban traffic applications.

The development of the basic technologies and the design phase are finished.

The production of the parts and the assembly of the flywheel and the bearings are in progress.

The power electronics and control cabinets are already finished and pretested.
### Dynastore

**Comparison of technologies**

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<tr>
<th></th>
<th>Conventional Flywheerl „Powerbridge“</th>
<th>Dynastore</th>
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<tbody>
<tr>
<td><strong>Usable Energy</strong></td>
<td>4 kWh</td>
<td>11 kWh</td>
</tr>
<tr>
<td><strong>Rated Power</strong></td>
<td>1200 kW</td>
<td>2000 kW</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>0.93</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>Stand By Losses</strong></td>
<td>10 kW</td>
<td>1 kW</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>7000 kg</td>
<td>1200 kg</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>D = 1500 mm, H = 2000 mm</td>
<td>D = 1500 mm, H = 600 mm</td>
</tr>
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</table>
Thank you for your attention