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The Conceptual Design of a Kinetic Energy Storage Device to Store 20 KWh of Energy

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The Concept Design of a Kinetic Energy Storage Device

Ertu Unver
Anthony Johnson

Visualisation of the Kinetic Energy Storage Device
Target Design Specification

- Envelope size: $1m^3$ approx
- Power rating: 20 to 50kWh
- Efficiency: $>75\%$
- Power degradation over 24hrs: $<10\%$
- Calendar life: 10 years
- Max sound power level: 63dBA
- Low speed: approx 20k rev/min
Flywheel Design Exploration

Flywheel Styles
1. Rim Type

2. Rim Type: Toroidal rotor with mag-lev bearings and motor/generator on outer rim.
   - Uses Eddy currents
   - 70% efficient
   - Large diameter coils
   - Difficult to control
   - Surface speeds at coils awkward to handle
Flywheel Design Exploration

3. **Rim Type:** with magnetic levitation bearings and motor/gen set on shaft.

- Uses Stator and Rotor Technology
- 90% efficient
- Small diameter coils
- Easy to control
- Coils easy to manufacture
- Surface speed at shaft within workable bounds
Flywheel Design Exploration

**Disc Type:** with magnetic levitation bearings and motor/gen set on shaft.

* Uses Stator and Rotor Technology
* 90% efficient
* Small diameter coils
* Easy to control
* Coils easy to manufacture
* Surface speed at shaft within workable bounds
Design Approach Overview

- Standard mechanical engineering techniques
- Use known technology approach where possible
- Use standard materials where possible
- Keep development to a minimum
Design Approach: Practical

Options
- Small – High Speed
- Large Low Speed

Disc Type
- Large diameter – axially thin
- Small diameter – axially long
Design Approach Disc Type Flywheel

Typical parameters were manipulated and iterated to reveal the **optimum solution** shown below:

<table>
<thead>
<tr>
<th>Dia</th>
<th>Depth</th>
<th>mass</th>
<th>Ang Vel</th>
<th>Surface</th>
<th>KE</th>
<th>KE</th>
<th>Power</th>
<th>1 tonne</th>
<th>Rim</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>m</td>
<td>kg</td>
<td>RPM</td>
<td>Speed</td>
<td>MJ</td>
<td>KWh</td>
<td>KW</td>
<td>Mass lift</td>
<td>Stress</td>
</tr>
<tr>
<td>0.60</td>
<td>0.50</td>
<td>1060</td>
<td>18000</td>
<td>566</td>
<td>318</td>
<td>24</td>
<td>6.6</td>
<td>8151</td>
<td>13</td>
</tr>
</tbody>
</table>

Diameter 600mm

Depth 500mm
Typical parameters were manipulated and iterated to reveal the **optimum solution** shown below:

### Design Approach: Rim Type Flywheel

<table>
<thead>
<tr>
<th>Outer Dia (m)</th>
<th>Inner Dia (m)</th>
<th>Depth (m)</th>
<th>Mass (kg)</th>
<th>Ang Vel (Rev/min)</th>
<th>Surface Speed (m/s)</th>
<th>Energy (MJ)</th>
<th>KE (KWh)</th>
<th>Power (KW)</th>
<th>1 tonne Mass Lift (m)</th>
<th>Rim Stress (MN/m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.45</td>
<td>1</td>
<td>928</td>
<td>18000</td>
<td>566</td>
<td>74.2</td>
<td>20.6</td>
<td>5.7</td>
<td>8151</td>
<td>13.1</td>
</tr>
</tbody>
</table>

Diameter 600mm

Depth 1000mm
Design Elements and Decisions

Disc-Type Flywheel (Solid)

Careful analysis required to account for

* Radial Stresses
* Hoop stresses
Design Elements and Decisions

Rim-Type Flywheel (Cylindrical)

Careful analysis required to account for

* Hoop stresses
Design Elements and Decisions

- **Surface speed 566m/s**: 1.6 x speed of sound
  Reduction of air turbulence drag and noise generation achieved by installing the rotor in a Vacuum Chamber

- **Reduction of frictional resistance:**
  - Apply Magnetic Levitation Bearings
    - Axial Bearings
    - Radial

SKF Magnetic Levitation Bearing
Design Elements and Decisions

Back-up Bearings

Should power fail to the magnetic levitation bearings a back-up set of **Rolling Element Bearings** will be applied.

Specialist Ceramic Bearings
Supplied by SKF
Design Elements and Decisions

Vacuum Chamber

- Encloses the flywheel rotor
- Contains the vacuum
- Uses only static seals (reduces frictional resistance)
Design Elements and Decisions

Motor / Generator

- External to main flywheel and vacuum chamber
- Modular unit can be changed easily
Design Elements and Decisions

Flywheel / Motor-Gen Coupling

- Flywheel Housing separate to Motor–Gen Housing
- Drive system needs to function across the sealed membrane.
- Apply magnetic coupling

Magna Drive Magnetic Coupling
Design Elements and Decisions

Containment Considerations

- Energy enough to lift a 1 tonne mass 8km vertically
- Dangers of burst are very real
  - 85MJ equivalent energy to 18kg (40 Lbs) of TNT

Two Containment Options:
- Heavy containment cylinder on a heavy foundation
- Light weight vacuum chamber encased in a concrete casing.
Design Elements and Decisions

Containment Option One

- Heavy Steel Containment
- Heavy Concrete Foundation

Heavy Casing

CONCRETE FOUNDATION
Design Elements and Decisions

Containment Option Two:
- Lightweight vacuum chamber encased in a concrete casing
- Includes sand bags radially mounted to act as a soft catch
Design Elements and Decisions

Containment Option Two: Concrete Basin with Sand Bag Soft-Catch

Containment with sand bag segments

Containment with sand bag segments showing internal arrangement
Concept One
Rim Type Flywheel

* Takes the form of a cylinder
* Diameter 600mm
* Length 1000mm
* Mass 930kg
Rim Type Flywheel

- **Style**: Hollow cylinder
- **Outer diameter (mm)**: 600
- **Inner diameter (mm)**: 450
- **Rotor depth (mm)**: 1000
- **Material**: steel
- **Density (kg/m³)**: 7500
- **Rotor mass (kg)**: 930
- **Angular velocity (Rev/min)**: 18000
- **Surface speed (m/s)**: 565
- **Energy (Joules)**: 74,200,000
- **Energy (kWh)**: 20.61
- **Power (kW)**: 5.73
- **1 Tonne mass lift (m)**: 8150
- **Containment (Primary)**: Steel casing
- **Containment (Secondary)**: Concrete lined Pit
- **Bearing system radial**: Magnetic Levitation
- **Bearing System (secondary)**: Rolling element Brgs
- **Motor-Generator Drive Coupling**: Magnetic
- **Chamber Type**: Vacuum
**Concept Two**

**Disc-Type Flywheel**

- Takes the form of a solid rotor
- Diameter 600mm
- Length 500mm
- Mass 1060kg
Disc Type Rotor

- **Style**: Solid cylinder
- **Outer Diameter (mm)**: 600
- **Inner diameter (mm)**: n/a
- **Rotor depth (mm)**: 500
- **Material**: Steel
- **Density (kg/m$^3$)**: 7500
- **Rotor mass (kg)**: 1060
- **Angular velocity (Rev/min)**: 18000
- **Surface speed (m/s)**: 565
- **Energy (Joules)**: 84,800,000
- **Energy (KWh)**: 23.55
- **Power (KW)**: 6.54
- **1 Tonne mass lift (m)**: 8,152
- **Containment (Primary)**: Steel casing
- **Containment (Secondary)**: Concrete lined Pit
- **Bearing system radial**: Magnetic Levitation
- **Bearing System (secondary)**: Rolling element Brgs
- **Motor Generator Drive coupling**: Magnetic
- **Chamber Type**: Vacuum
### Selection of Concept

<table>
<thead>
<tr>
<th>Rim Type</th>
<th>Disc Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Lower mass 930kg</td>
<td>- Higher mass 1060kg</td>
</tr>
<tr>
<td>- Height overall 1877mm</td>
<td>- Overall height 2028mm</td>
</tr>
<tr>
<td>- Energy 20.61 kWh</td>
<td>- Energy 23.55 kWh</td>
</tr>
<tr>
<td>- Power 5.73 kW</td>
<td>- Power 6.54 kW</td>
</tr>
<tr>
<td>- Stresses in rim only</td>
<td>- Radial and Hoop stresses present</td>
</tr>
<tr>
<td><em>(Less prone to burst)</em></td>
<td></td>
</tr>
</tbody>
</table>

- Design and manufacturing will present a similar level of difficulty
- Balancing relatively easier with the rim-type flywheel
- Cost implications will be similar for each type
Overall Concept

**Modular construction allows:**
- Ease of Maintenance
- Ease of Assembly
- Standardised Components

**Concrete containment can be:**
- Free Standing
- Buried
Overall Concept

Single Concrete Containment Basing showing Lid and Control System
6 x sand bags in case of failure
6 x sand bags in case of failure
Overall Concept

Envisaged Industrial Application (lead removed)
Overall Concept

Envisaged Industrial Application (lead removed)
Overall Concept

Envisaged Industrial Application (lead removed)
Overall Concept

General Scale Visualisation
Overall Concept: Industrial
Overall Concept – Solid
Visualisation of the Kinetic Energy Storage Device
Overall Concept - Hollow

Visualisation of the Kinetic Energy Storage Device
Overall Concept

Visualisation of the Kinetic Energy Storage Device
Work Required to Progress the Project

- Finite element stress analysis vacuum chamber
- Mag/Lev radial bearing design
- Mag/Lev axial bearing design
- Control system for magnetic levitation bearings
- Machine monitoring system
- Design and manufacture of motor / generator set
- Control system for the motor / generator set
- Stress analysis of rotors for burst limitation
- Fluid flow analysis within the chamber
- Vacuum pump and equipment selection
- Rolling element bearing design and selection
- Vacuum casing design
- Explosion containment system design
- Foundations design
- Selection of materials
Questions?