Advanced Electric Machines Technology

Workshop on Future Large CO2 Compression Systems
sponsored by
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Konrad Weeber
GE Global Research
weeber@ge.com
Mechanically Driven Compressors

Mechanical Drive Benefits

• Historical solution with large installed reference base
• High ratings available
• Independent of electricity supply infrastructure

Mechanical Drive Disadvantages

• Speed control & turn-down
• Low system efficiency
• Site emissions
• Site noise impact
• GT maintenance cycle

Typical compression train configurations
Electrically Driven Compressors

**Electrical Drive Benefits**
- Improved speed control
- Higher system efficiency
- No site emissions
- Reduced site noise impact
- Reduced maintenance, increased uptime
- Dynamic braking capability
- Short start-up time and load assumption
- Enable tight integration of drive motor with compressor

**Electrical Drive Challenges**
- Requires availability of electricity on site
- Power ratings have to be met by both motor and frequency converter ("drive")
- Required foot-print and weight associated with frequency converter

**Geared Electric Drives**
- “low-speed” motor supplied by VFD
- Step-up gear-box

**High-Speed Electric Drives**
- “high-speed” motor supplied by “high-frequency” VFD
- Gear box eliminated
- Motor either stand-alone or integrated with compressor
High-Speed Multi-MW Drive Motors

Wound-field synchronous machines
- Highest speed typically ~7500 rpm
- Higher speeds limited by mechanical support of field winding
- 50-80 MW below 4000 rpm

Induction machines
- Widest application of “high-speed” multi-MW machines
- Laminated & solid rotor design

Permanent magnet machines
- New emerging technology
- Improved efficiency
- Robust rotor technology
- Preferred choice above ~ 15,000 rpm
Integrated Motor-Compressor

Integration Characteristics
- Direct coupling of motor & compressor rotors
  - No gear box
- Motor shares casing with compressor
- No rotating shaft component penetrates pressure vessel
  - No shaft-end seals
- Power train levitated by magnetic bearings
  - Oil-free system
- Motor cooled with process gas
  - No External cooling system

CAPEX Benefits
- No gear
- Simplified auxiliaries (no lube oil & oil cooling)
- Smaller footprint & weight

OPEX Benefits
- Reduced down-time for maintenance
- Unmanned operation & remote control
- No site emissions
- Reduced noise

Challenges
- Process gas compatibility of motor
- Especially for sour gas, acid gas, wet gas

6 MW 12,000 rpm prototype
With laminated-rotor induction machine
Hermetically Sealed Compression

Clean gas applications
- Motor cooled with process gas
- Stator and AMBs are not encapsulated
- Substantial simplification of compression station compared to geared electric drive

Sour gas applications
- Motor cooled with process gas
- Stator and AMBs are encapsulated
- All materials exposed to process gas are NACE compliant
- Hermetically sealed for subsea compression & acid gas injection
Permanent Magnet Rotor Technology

**Configuration**
- Rare-earth permanent magnet rotor poles
- Metallic retaining ring
- Rigid rotor design
- Multi-plane rotor balance
- Magnetization after assembly

**Technology Benefits**
- Robust manufacturing process
- No active rotor components
- Minimal heating and thermal cycling
- Best efficiency
- Materials in contact with process gas are NACE compliant

Most Robust Architecture for High-Speed
Motor Technology Development

- Manufacturing process
- Rotor mechanical design
- Rotor-dynamic design
- Bearing technology
- Magnetization process
- High-frequency stator design
- Stator encapsulation

Sub Scale Rotors:
1 MW  17,000 rpm

Reduced (1/6) Length
Same Cross Section

Full Scale Prototype Rotor
6 MW  17,000 rpm
Demonstration Spin Rotor

Set up
- Rotor with full-size cross section
- Exposed magnet-to-shaft plane for instrumentation
- Pendulum-style spin pit

Proof test @ 125% speed (21,250 rpm)
- Performed at 3 different temperatures
- No observed dynamic instability
- No dimensional changes
- No signs of damage
  - **Structural integrity**
  - **Thermal stability**
  - **Balance Stability**
Magnetization Process

Novel Aspects of this PM rotor

• Single-shot magnetization
• Magnetization through retaining ring

Results

✓ Accomplished target magnetization level
✓ Uniform magnetization levels pole-pole
✓ Magnetization through retaining ring
✓ Mechanical integrity

➢ Largest PM rotor built to date for single-shot magnetization
Rotor-Dynamic Spin Tests

Set up
- Full-size prototype rotor (6 MW @ 17,000 rpm)
- Active magnetic bearings
- Geared drive motor
- “No-load” mechanical spin tests

Primary Objectives
- Confirm mfg process for full-size rotor
- Validate rotor-dynamic response of rotor
- Validate rotor support by magnetic bearings
- Perform magnetic bearing drop tests
Rotor-Dynamic Spin Tests

6 MW  17,000 rpm  
Demonstration Rotor

Set up

• Full-size prototype rotor
• Active magnetic bearings
• Geared drive motor
• “No-load” spin tests

World record - highest-rated PM @ rated
Hermetically Sealed Stator

Electrical Insulation System
- Electrical operating parameters:
  - Rated line-line voltage: 4.16 – 6.6 kV
  - Fundamental frequency: 333 – 666 Hz
- Class F system operated @ class B rise
- Standard inverter-duty VPI system

Hermetic Encapsulation
- Fully encapsulated stator winding
- NACE compliant materials at gas interface
- Conduction-cooled by process gas

5 MW Prototype

5 MW 17,000 rpm
# High Speed Electric Compression

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<th>Clean gas</th>
<th>Subsea compression</th>
<th>Raw gas / sour gas</th>
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<td><strong>APPLICATIONS</strong>&lt;br&gt;Gas storage and small pipeline &amp; clean gas applications for upstream&lt;br&gt;&lt;br&gt;<strong>GE SOLUTION</strong>&lt;br&gt;- Integrated &amp; stand alone HSEMC&lt;br&gt;- Motor cooled by process gas&lt;br&gt;- Oil-free solution&lt;br&gt;&lt;br&gt;<strong>ADVANTAGES</strong>&lt;br&gt;- oil-free, seal-less design&lt;br&gt;- unmanned solution&lt;br&gt;- Compactness.. less infrastructure&lt;br&gt;- Lower CAPEX &amp; OPEX … low maintenance</td>
<td><strong>APPLICATIONS</strong>&lt;br&gt;Subsea / wet gas compression&lt;br&gt;&lt;br&gt;<strong>GE SOLUTION</strong>&lt;br&gt;- “Marinized” integrated HSEMC&lt;br&gt;- motor cooled by process gas&lt;br&gt;- raw / wet gas design&lt;br&gt;- Vertical &amp; horizontal design&lt;br&gt;&lt;br&gt;<strong>ADVANTAGES</strong>&lt;br&gt;- oil-free, seal-less design&lt;br&gt;- Reliability … robustness&lt;br&gt;- Zero maintenance&lt;br&gt;- Small footprint / weights… easy handling</td>
<td><strong>APPLICATIONS</strong>&lt;br&gt;Acid / sour gas injection, aging wells boosting etc.&lt;br&gt;&lt;br&gt;<strong>GE SOLUTION</strong>&lt;br&gt;- Integrated HSEMC with gas cooled Motor (“raw gas” design)&lt;br&gt;- HS stand alone motor&lt;br&gt;&lt;br&gt;<strong>ADVANTAGES</strong>&lt;br&gt;- Oil-free, seal-less design&lt;br&gt;- More compact… reduced footprint&lt;br&gt;- Low maintenance … Increased safety</td>
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R & D Needs

• Advanced Stator and Rotor cooling schemes

• Improved materials for high speed rotors, advanced design tools

• Advanced Stator and Rotor materials to handle corrosive gases

• Improved drive electronics
  - higher fundamental frequencies for high speed machines
  - improved controls and bandwidth to provide low torque ripple

• Tighter integration of compressor, motor and drive components and engineering.
Thank you

Q & A