Advanced Electric Machines Technology

Workshop on Future Large CO2 Compression Systems
sponsored by
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imagination at work

Mechanically Driven Compressors

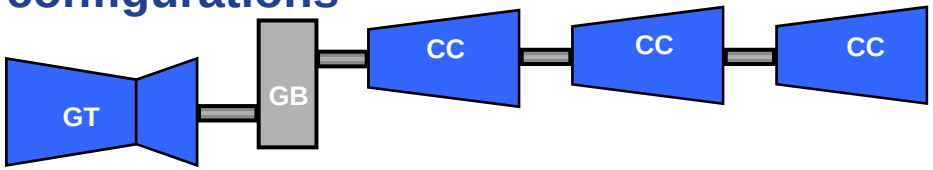
Mechanical Drive Benefits

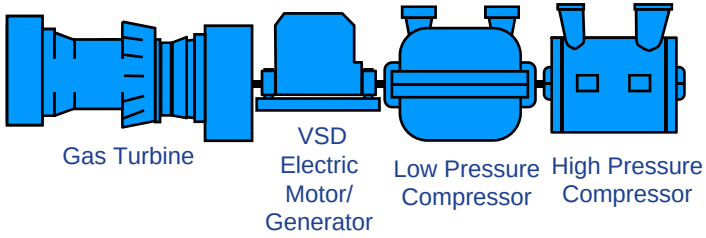
- Historical solution with large installed reference base
- High ratings available
- Independent of electricity supply infrastructure

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

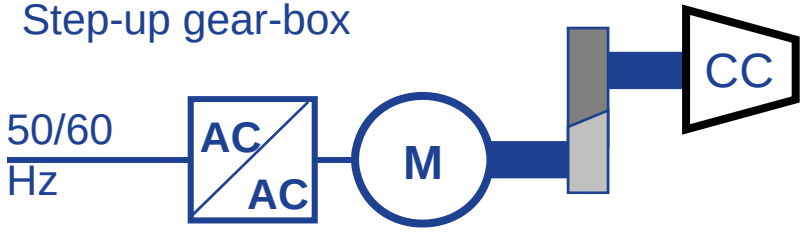
- Improved speed control
- Higher system efficiency
- No site emissions
- Reduced site noise impact
- Reduced maintenance, increased uptime
- Dynamic braking capability
- Short start-uptime and load assumption
- Enable tight integration of drive motor with compressor

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

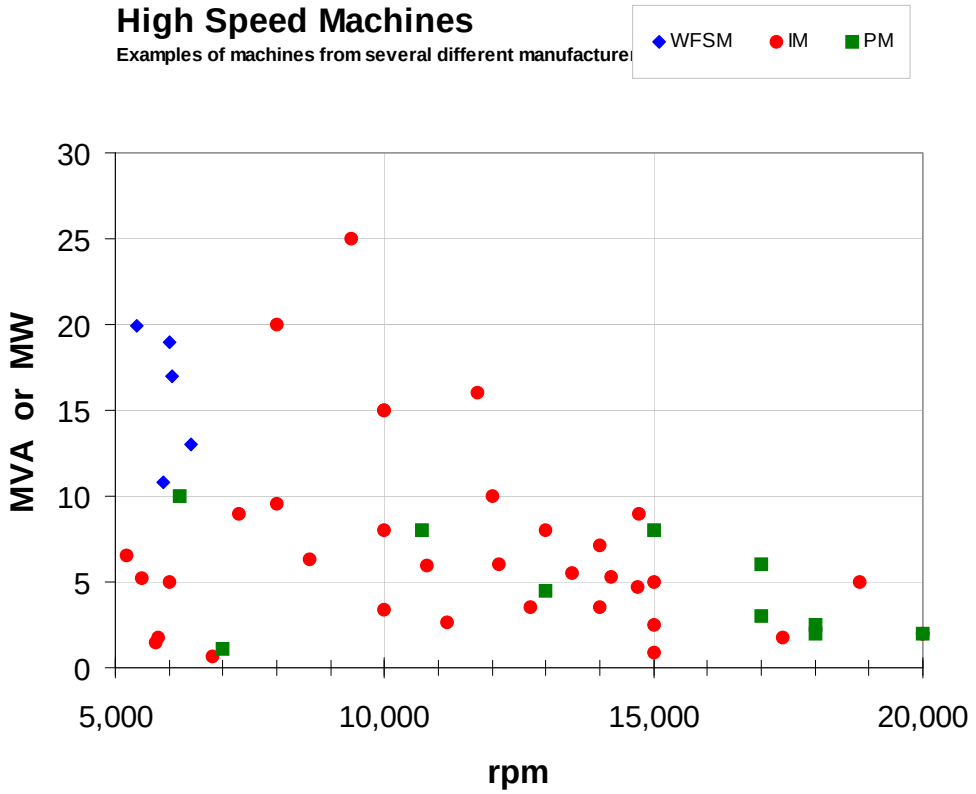
- Highest speed typically ~7500 rpm
- Higher speeds limited by mechanical support of field winding
- 50-80 MW below 4000 rpm

Induction machines

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

Permanent magnet machines

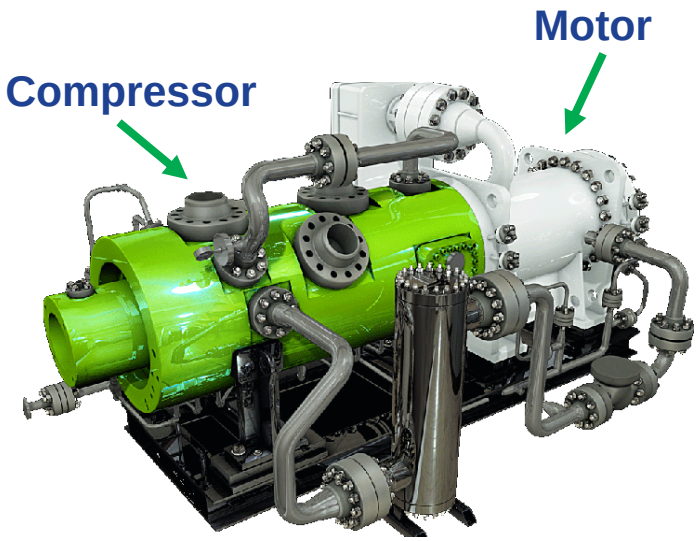
- New emerging technology
- Improved efficiency
- Robust rotor technology
- Preferred choice above ~ 15,000 rpm



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**



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

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 ……

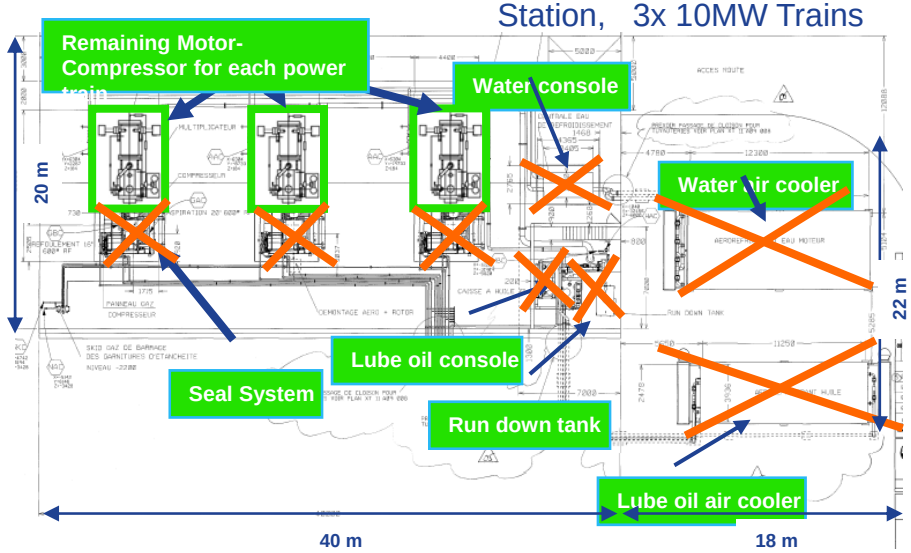
Hermetically Sealed Compression

Clean gas applications

- Motor cooled w process gas
- Stator and AMBs are not encapsulated

➢ **Substantial simplification of compression station compared to geared electric drive**

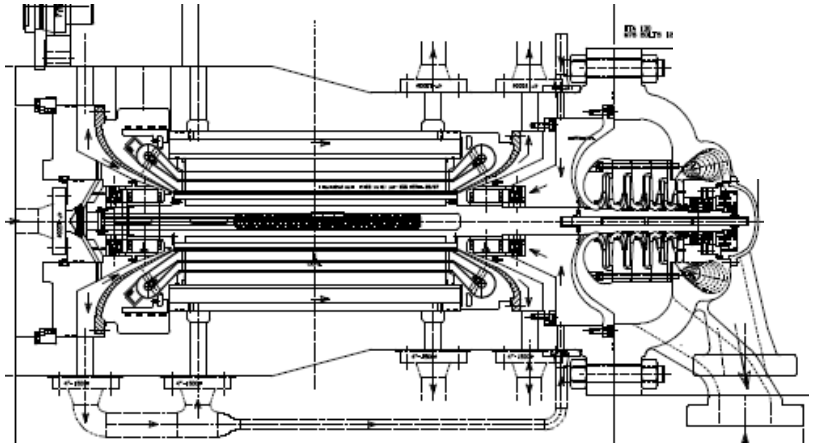
Plot Plan of a Conventional Land Based Compression Station, 3x 10MW Trains



Sour gas applications

- Motor cooled w process gas
- Stator and AMBs are encapsulated
- All materials exposed to process gas are NACE compliant

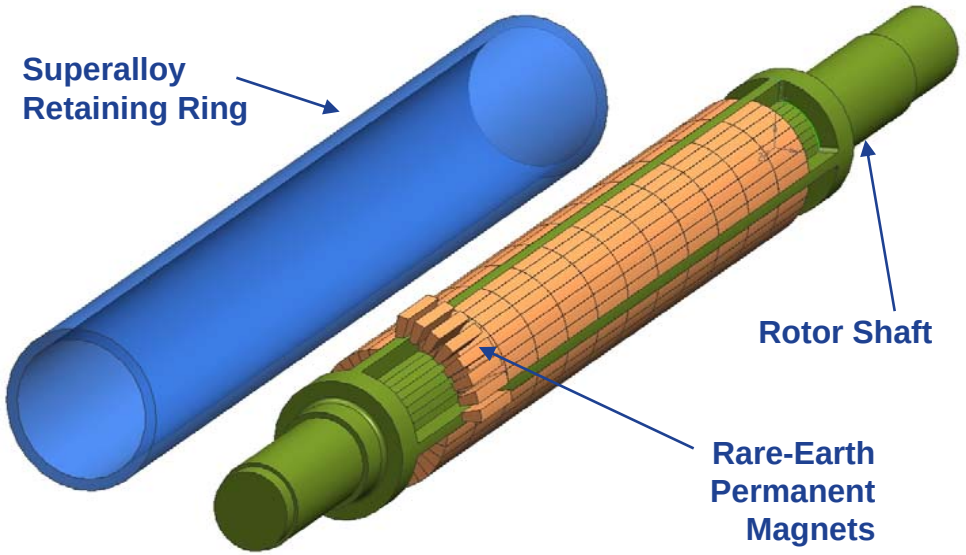
➢ **Hermetically sealed for subsea compression & acid gas injection**



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

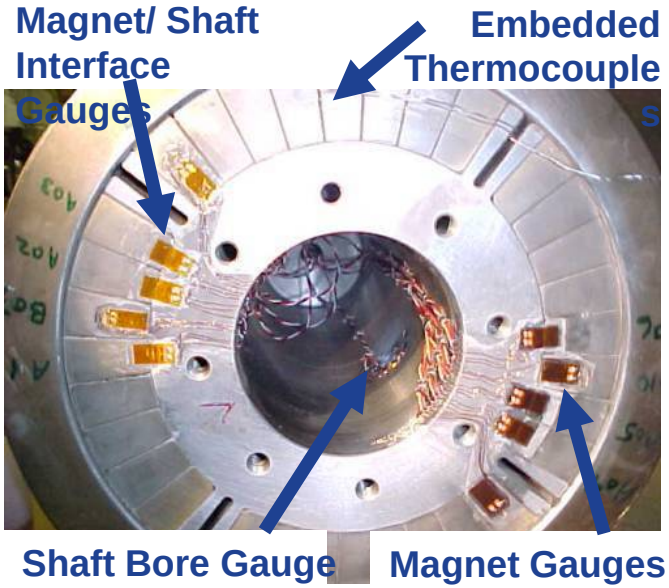
Demonstration Spin Rotor

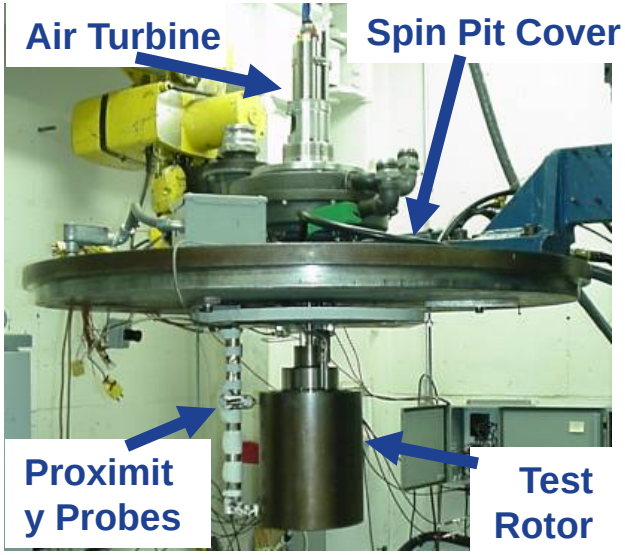
Set up

- 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**

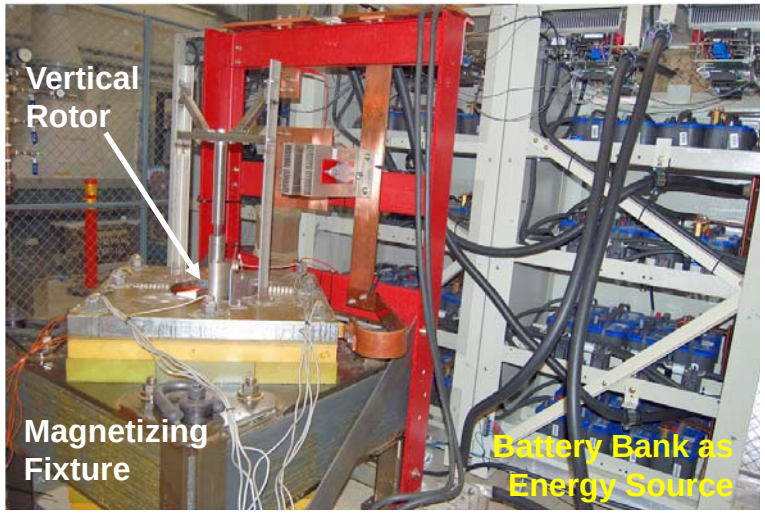




Magnetization Process

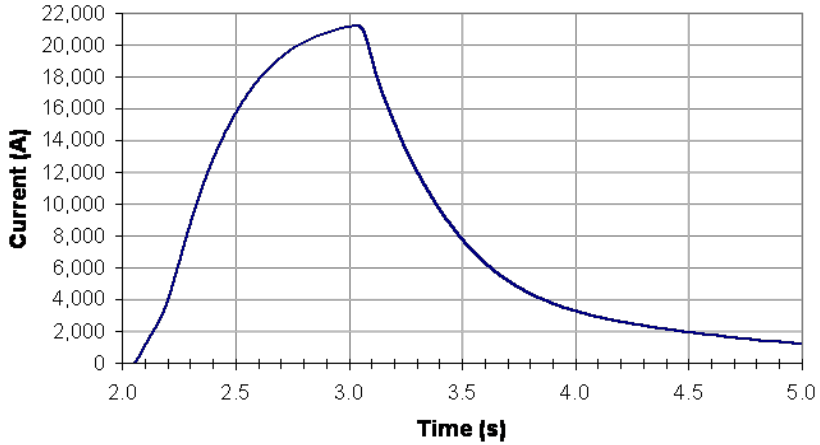
Novel Aspects of this PM rotor

- 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**

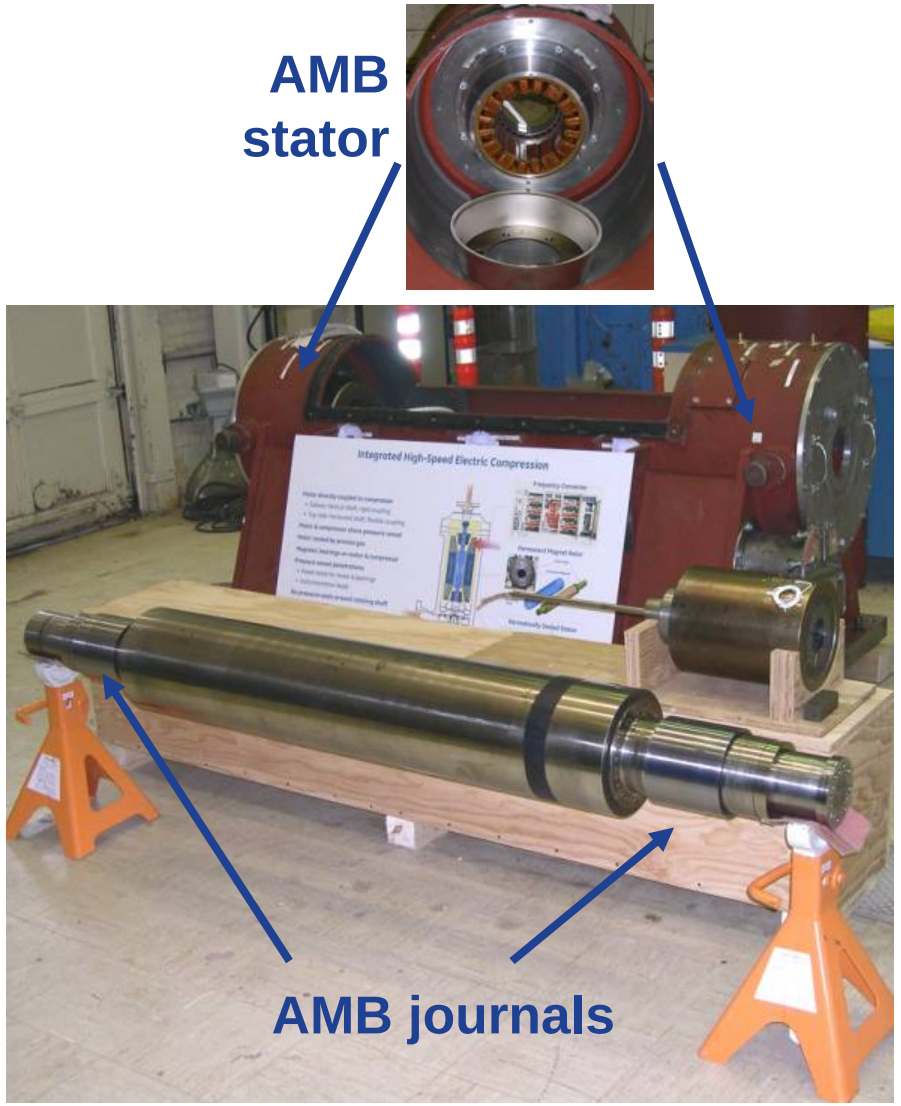
Rotor-Dynamic Spin Tests

Set up

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

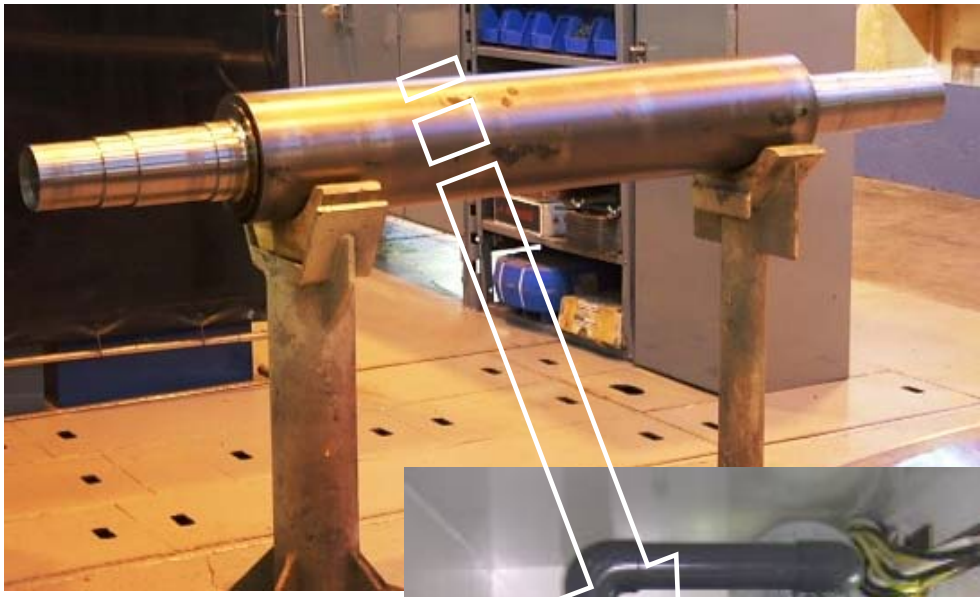
Primary Objectives

- 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

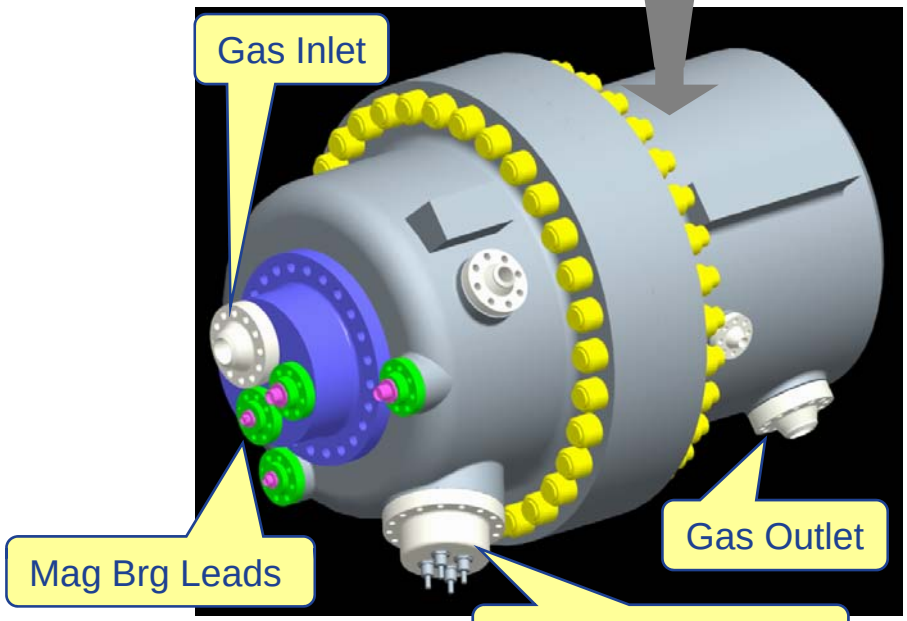
Electrical Insulation System

- 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



High Speed Electric Compression

Clean gas

APPLICATIONS

Gas storage and small pipeline & clean gas applications for upstream

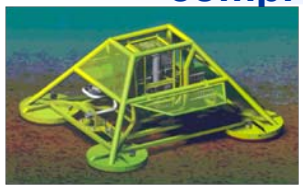
GE SOLUTION

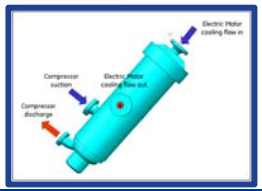
- Integrated & stand alone HSEMC
- Motor cooled by process gas
- Oil-free solution

ADVANTAGES

- oil-free, seal-less design
- unmanned solution
- Compactness.. less infrastructure
- Lower CAPEX & OPEX … low maintenance

Subsea compression





APPLICATIONS

Subsea / wet gas compression

GE SOLUTION

- "Marinized" integrated HSEMC
- motor cooled by process gas
- raw / wet gas design
- Vertical & horizontal design

ADVANTAGES

- oil-free, seal-less design
- Reliability … robustness
- Zero maintenance
- Small footprint / weights… easy handling

Raw gas / sour gas

APPLICATIONS

Acid / sour gas injection, aging wells boosting etc.

GE SOLUTION

- Integrated HSEMC with gas coole
Motor ("raw gas" design)
- HS stand alone motor

ADVANTAGES

- Oil-free, seal-less design
- More compact… reduced footprin
- Low maintenance … Increased safety

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