The 6th International Supercritical CO_2 Power Cycles Symposium
March 27 - 29, 2018, Pittsburgh, Pennsylvania

Magnetic Bearings for Supercritical CO_2 Turbo Machinery

By

Richard Shultz

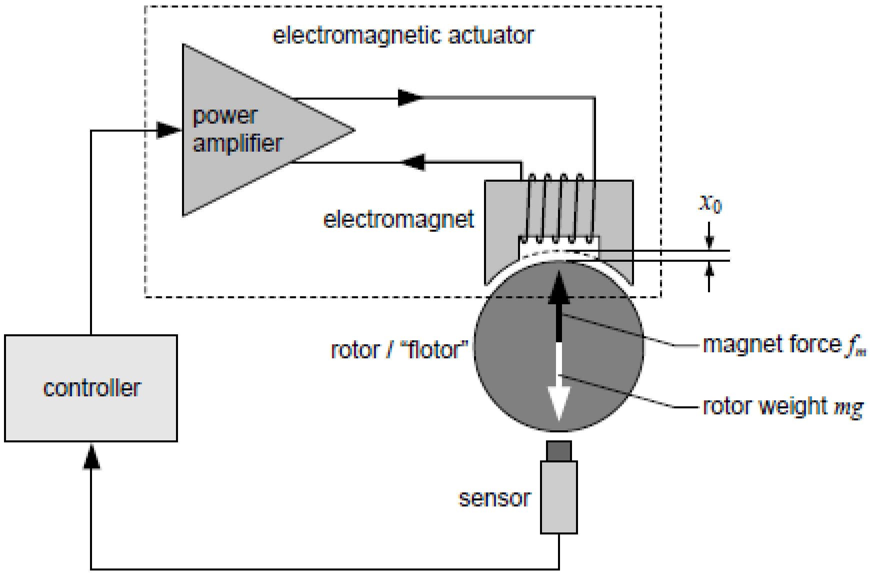
Ashwanth Narayanaswamy

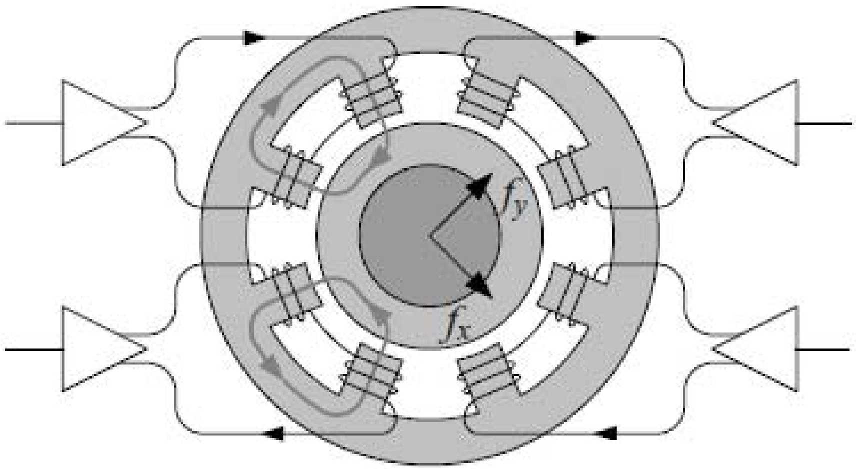
oduction

- High potential of supercritical $C0_2$ Brayton cycles to improve thermodynamic efficiencies in electric power generation
- Turbomachinery and rotating equipment technology is under review and development
- Key design input challenges that can potentially put conventional bearings at a disadvantage
    - High startup thrust loads (Max thrust load capacity required at zero speed)
    - High Speeds
    - High Fluid Density
    - Extreme Temperature Ranges
- Active Magnetic Bearing (AMB) technology can be used to address these challenges effectively (has been used for over 30 years).
- We are designing an Active Magnetic Bearing system for an SC02 Turbine
- **Objective of this paper:**

  Compare the requirements of the bearing systems in supercritical CO2 machines with capabilities of the AMB system

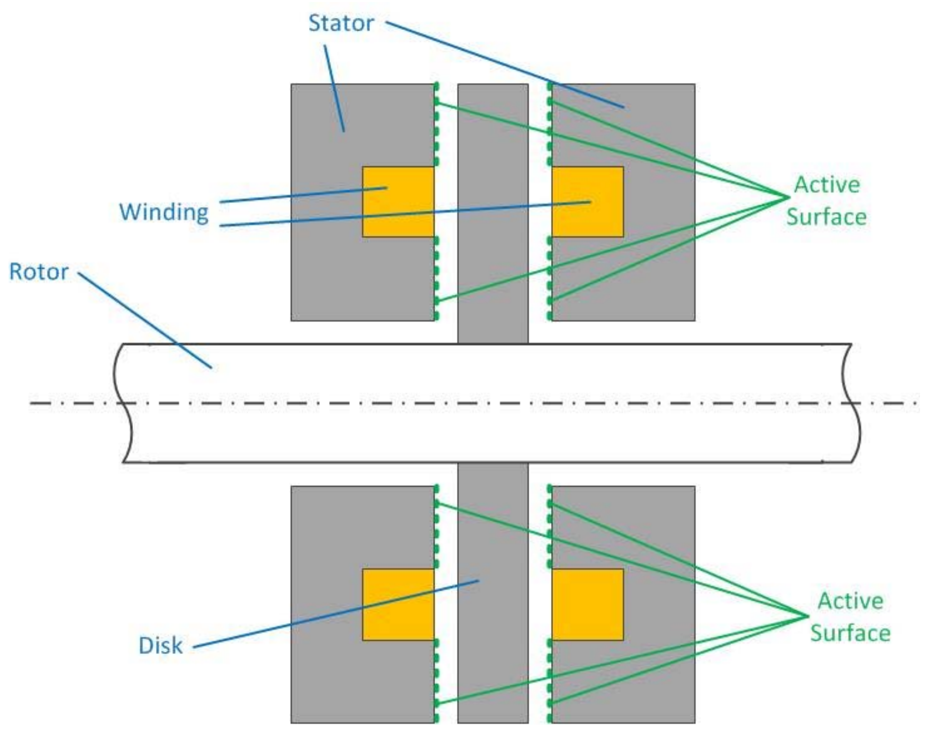
ive Magnetic Bearing – General Overview





- The primary components are –
  - Electro magnets (coils wound on stator lamination stacks)
  - Rotor
  - Sensor
  - Controller
  - Power amplifier

al AMB – Primary Components



- The primary components are –Stators with slots for coils, Coils, Thrust Collar (disk), sensors and control system.
- The thrust collar rotates with the shaft of the machine and provides part of the magnetic flux circuit for the actuator

al AMB-contd…

- Magnetic force from an actuator:

$$F = \frac{B^2 . S}{2 . \mu_0}$$

Where B is the magnetic flux density, S is the total pole projected area, and μ_0 is the permeability of free space.

- Magnetic flux density saturates between 1.3 and 1.4 Tesla for most materials. So the bearing load capacities are highly dependent on pole projected area.

- For high-speed applications, ‘ultra-high strength’ ferrous alloys have been identified for the thrust collar with satisfactory magnetic properties. Peripheral speed capability of the magnetic bearing thrust collar has increased from approximately 450 m/s to 675 m/s.

al AMB-contd…

- Also with special mechanical design considerations(like dual thrust disk design), the load capacity has been maximized.

- Owing to these developments, the maximum speed capability and maximum load capacity of the axial AMB has been maximized.

llenge : High Start-up thrust load in SCO_2 Turbomachinery

- High thrust loads are caused by the shutoff pressure surrounding the impeller acting on the shaft cross sectional area at the shaft seal

- Maximum thrust load at 0 speed, moderates at high speed

- Advantages of using AMB technology
  - ✓ No shaft rotation required for bearing lift off
  - ✓ Maximum steady state radial and thrust load capacity available from 0 to max speed
  - ✓ No time limit for operation(for stabilizing) at intermediate speeds. This eliminates the need for special controls needed for extreme run up curves.

llenge : Thermal distortion at high speeds

- SCO_2 turbomachinery designs have a high temperature gradient along the length of the rotor, which due to thermal distortion, can lead to relatively high levels of rotating unbalance, especially at high speeds

- . Advantages of using AMB technology
  - ✓ The synchronous control algorithms allow the rotor to rotate around its inertial axis drastically decreasing the force transmitted to the housings and enabling reliable operation.

llenge : High Fluid Density in SCO2 Turbomachinery

- While high fluid density increases cycle efficiency, it also increases destabilizing cross coupled stiffness from seals.
- At low speeds, the bearings must provide high levels of damping to stabilize the seal effects and traverse the rigid body modes with low vibration levels;
- At high speeds, the high levels of damping are needed to avoid sub synchronous instabilities of the rigid body modes
- . Advantages of using AMB technology
  - ✓ With magnetic bearings, the stiffness and damping coefficients at the rigid body mode frequencies will not vary with rotating speed, providing consistent stability over the operating speed range.

llenge : Extreme Temperatures

- Supercritical CO2 Brayton cycles use high temperatures to increase efficiency.
- Any bearing requiring liquid lubricants will not be capable of operating in excess of 400ºC.
- Extreme temperatures in SCO_2 equipment cause high thermal dimensional expansion of housings and shafts. In conventional bearing designs, this can lead to misalignment and clearance variation between rotor and stator components.

llenge : Extreme Temperatures (contd…)

- . Advantages of using AMB technology
  - ✓ AMB systems have been successfully applied in environments with operating temperatures ranging from -196ºC (liquid nitrogen) to 450ºC (gas turbine exhaust).
  - ✓ Magnetic bearings provide robustness against variations in alignments and clearances due to the relatively large clearances used, (range from 0.75mm to 2 mm). Conventional bearings have gaps on the order of 0.050 mm
  - ✓ Constant stiffness and damping coefficients can be maintained , compared to conventional bearings owing to comparatively larger clearances

VELOPMENT BENEFITS – SCALABLE TECHNOLOGY

- Supercritical CO_2 Brayton cycle projects are mostly in the demonstration phase at this time, (relatively low-power, scaled machines compared to the full-size power equipment).
- As size and/or speed of machines increase, so must the dynamic load capability of the magnetic bearings (generated by slewing the current to the windings of the magnetic bearing actuator).
- The power ratings of state-of-the-art magnetic bearing system power amplifiers range from 120 volts/4 amps up to 600 volt/60 amps. Hence, scalable.
- Magnetic bearings are an easily scalable technology (size of the mechanical bearing components & capabilities of the control electronics).
- High speed magnetic bearing applications
  - ✓ rotor masses of a few kilograms up to 10 tons.
  - ✓ rotor outside diameters ranged from 25 mm to 550 mm.

VELOPMENT BENEFITS-PROCESS FORCE MEASUREMENT

- Measuring aerodynamic forces:
  - ✓ Magnetic bearings have the ability to measure the forces reacted by the bearings, including the steady state forces and the dynamic forces
  - ✓ can be used to measure the transfer function of the rotor-bearing system to determine the destabilizing forces due to aerodynamic effects.
  - ✓ Forces reacted by bearings can be related to measurable parameters-current and displacement.

- The use of magnetic bearings to measure forces and dynamic characteristics within supercritical CO_2 machines will provide a vital tool for designing the full size machines for the final power plant implementations of the technology.

RROSIVE ENVIRONMENTS

- ✓ Canned magnetic bearings would provide a robust selection for corrosive environments.
- ✓ Canned magnetic bearings have a thin corrosion resistant lining that hermetically seals the bearing stators and sensors from the process fluid.
- ✓ For supercritical CO_2 applications where water content is negligible, uncanned magnetic bearings may be operated while immersed in the process fluid.

MMARY

- Magnetic bearing systems provide a fully levitated rotor at zero speed conditions; Hence, the AMB system can provide the maximum steady state load capacity at zero speed and at maximum speed.

- With the ultra-high strength alloys, together with special mechanical design considerations, the maximum peripheral speed capability of the magnetic bearing thrust collar is now 675 m/s.

- For magnetic bearings, the stiffness and damping coefficients versus frequency characteristic has very small variation due to
  - ❑ rotating speed change
  - ❑ thermal expansion effects and
  - ❑ temperature change.

MMARY

- Magnetic bearings are an easily scalable technology, (component size and capabilities of the control electronics); High speed magnetic bearing applications –applied to rotor masses of a few kilograms up to rotor masses of 10 tons.

- Canned and conventional magnetic bearing designs will provide robust service in corrosive or non-corrosive supercritical CO2 environments.

- The use of magnetic bearings to measure forces and dynamic characteristics within supercritical CO2 machines will provide a vital tool for designing the full size machines for the final power plant implementations of the technology.

DOVER®