Spiral Magnetic Gradient Motor Using Axial Magnets

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http://www.ias-spes.org/SPESIF.html

Credit: Tom Schum for spiral stator construction
Gradients Are Used for All Power

- Thermal gradient is used for heat pump
- Voltage gradient is used for electricity “pumping” of current
- Gravity gradient is used for hydroelectric power
- Pressure gradient is used for natural gas and water pumping
- Magnetic gradient is used for nothing so far
Inhomogeneous Magnetic Fields = Magnetic Gradient

The Stern–Gerlach Experiment and Electron Spin

--Modern Physics, Schaum’s Outline Series, Gautreau et al., McGraw Hill, 1978

21.1 THE STERN-GERLACH EXPERIMENT

In the Stern–Gerlach experiment, performed in 1921, a beam of silver atoms having zero total orbital angular momentum passes through an inhomogeneous magnetic field and strikes a photographic plate, as shown in Fig. 21-1. Any deflection of the beam when the magnetic field is turned on is measured on the photographic plate.

Their experimental setup: The magnetic field B is more intense near the pointed surface at the top than near the flat surface below, creating a slope in a graph of B vs. z, which is the gradient dB/dz.

Two experimental examples that utilize the magnetic field gradient

The net Force created on the ball bearing = the magnetic field gradient multiplied by the induced magnetic moment, as with the Stern-Gerlach Experiment

Hartman Patent #4,215,330

Beam of silver atoms

Fig. 21-1

Inhomogeneous magnetic field

Photographic plate

The purpose of the inhomogeneous magnetic field is to produce a deflecting force on any magnetic moments that are present in the beam. If a homogeneous magnetic field were used, each magnetic moment would experience only a torque and no deflecting force. In an inhomogeneous magnetic field, however, a net deflecting force will be exerted on each magnetic moment \( \mu \). For the situation of Fig. 21-1,

\[
F_z = \mu \cos \theta \frac{dB}{dz}
\]

where \( \theta \) is the angle between \( \mu \) and B, and \( dB/dz \) is the gradient of the inhomogeneous field.
Spiral Magnetic Motor (SMM) Uses the Magnetic Gradient

\[ F_\theta = M \cos \phi \frac{dB}{d\theta} \]

\[ F_z = \mu \cos \phi \frac{dB}{dz} \]

Hartman Patent 4,215,330
Spiral Magnetic Motor (SMM)

Archimedean spiral is used for SMM stator magnets where \( r = 6 + \theta/2 \) and \( B(r) \) is linearly dependent on \( \theta \).

\[ F = \nabla U \quad \text{where} \quad U = M \cdot B \quad \text{and} \]

\[ U = M_r B_r + M_\theta B_\theta \]
SMM Governing Equations

\[ F = \frac{M}{r} \frac{\partial B_r}{\partial \theta} + M \frac{\partial B_r}{\partial r} \]

\[ T = M \frac{\partial B_r}{\partial \theta} \]

\[ W = \int T \, d\theta \]

Maximize radial B field \((B_r)\) for maximum torque

ENERGY DENSITY CONSIDERATIONS: \(B\)-FIELD = 50K \(\times\) \(E\)-FIELD

\[ U_B = \frac{1}{2} \frac{B^2}{\mu_o} \]

For a maximum B field in air of 20 kG (2 Tesla), \(U_B = 2 \text{ MJ/m}^3\)

\[ U_E = \frac{1}{2} \varepsilon_o E^2 \]

For a maximum E field in air of 3 MV/m, \(U_E = 40 \text{ J/m}^3\)

2,000,000 = 40 \(\times\) 50,000!
Six SMM designs were tested: 1, 3, 4, 6, 10” rotors.

- ▲ = rotor
- ♦ = stator magnetic flux density
Spiral Magnetic Motor Angular Velocity

Angular Displacement (radians)

Angular Velocity (rad/sec)

1" rotor
3" rotor
4" rotor
6" rotor
10" rotor
Poly. (4" rotor)

Data acquisition limit

Polynomial Fit
Peak KE, Back Torque, Mass, B-Field

5 Rotors Tested: 1.25”, 3”, 4”, 6”, 10”

10” rotor: 0.80 joules

Phototransistor detail
Angular Displacement (degrees)

10" Rotor Torque (N-m)

10" Rotor Potential Energy (J)

Negative Work Region

Positive Work Region

$W = \int T \, d\theta$

Positive net work required to move latched rotor at 315° to end (starting point) at 360°:

$W = 0.52 \text{ Joules}$

when starting at 0.78 J KE

10” rotor tests

Torque Measurement $T = rxF$
Place metal plate of particular permeability underneath rotor in order to produce:

Favorable Hysteresis Currents

Hysteresis Depends on Permeability and Resistivity*

\[
\frac{B}{\mu H} = 1 - \frac{8}{\pi^2} e^{-\beta t}
\]

\[
\beta = \frac{\pi \rho}{(4 \mu \delta^2)}
\]

Designing the Growth of Eddy Currents to Match Rotation Speed

Choosing \textit{aluminum or copper} for example, the permeability will be the same as free space \((\mathcal{O}_0 = 4\pi \times 10^{-7})\), which is very low and the resistivity is also low. Choosing an aluminum plate that is about a centimeter (1 cm) thick would also be a good choice since the thickness of the sheet "delta" is squared and also in the numerator. Altogether, the calculation shows a relatively slow build-up over a tenth of a second and only about 30% at a millisecond after the stator field magnet is applied to the rotating disk, which is in keeping with a delayed eddy current that would push instead of retard the changing flux as would be normally expected from Lenz’ Law.

\(\square = \text{resistivity}, \mathcal{O} = \text{permeability}, \delta = \text{thickness of plate}, H \text{ field is suddenly applied}\)

**New frontiers in magnetics**

**Wiegand’s wonderful wires**

Wiegand wires are FeCoV bistable Vicalloy metal with 2 regions

US 1973 patent # 3,757,754

Used for years for auto ignitions

Provides repeatable magnetic pulse

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**Comparison of pulse generators used in electronic ignition**

<table>
<thead>
<tr>
<th></th>
<th>Signal-noise ratio</th>
<th>Rate sensitivity</th>
<th>Temperature range (°F)</th>
<th>Gap sensitivity</th>
<th>Electrical input</th>
<th>Pulse amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WIEGAND EFFECT</strong></td>
<td>Very good</td>
<td>Not rate sensitive</td>
<td>-95 to +500 (approx.)</td>
<td>Minimal</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td><strong>VARIABLE RELUCTANCE</strong></td>
<td>Fair</td>
<td>Poor</td>
<td>-95 to +500 (approx.)</td>
<td>Critical</td>
<td>Not required</td>
<td>Millivolts to volts</td>
</tr>
<tr>
<td><strong>HALL EFFECT</strong></td>
<td>Poor</td>
<td>Good</td>
<td>-40 to +275</td>
<td>Moderate</td>
<td>Required</td>
<td>Millivolts</td>
</tr>
<tr>
<td><strong>LED</strong></td>
<td>Poor</td>
<td>Not rate sensitive</td>
<td>-40 to +275</td>
<td>Minimal</td>
<td>Required</td>
<td>Millivolts</td>
</tr>
</tbody>
</table>

**Wiegand causes Barkhausen jumps of magnetic domains that align quickly**

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Inverse magnetostrictive (MS) effect combined with a piezoelectric material (PZT) and voltage

**Comparison of Power Consumption of Electromagnet and Device in Static and Dynamic Operation**

<table>
<thead>
<tr>
<th></th>
<th>E.M.</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static operation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max input voltage</td>
<td>2</td>
<td>200</td>
</tr>
<tr>
<td>Power consumption</td>
<td>3.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Dynamic operation (10Hz)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max input voltage</td>
<td>2</td>
<td>200</td>
</tr>
<tr>
<td>Power consumption</td>
<td>1.2</td>
<td>0.27</td>
</tr>
<tr>
<td><strong>Dynamic operation (100Hz)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max input voltage</td>
<td>2</td>
<td>200</td>
</tr>
<tr>
<td>Power consumption</td>
<td>1.2</td>
<td>2.47</td>
</tr>
</tbody>
</table>

Fig. 1. Configuration. Terfenol-D and stack PZTs bonded to iron yokes are applied pressure by nonmagnetic stainless bolts via Belleville springs.
Magnetic Switching for SMM

Piezoelectric Actuator that bends with very little voltage applied

IRI V-Track Dual SMM with Radial Magnets
Switching can be applied to the top stator magnet
Multi-Stage SMM