Magnetic Levitation Experiments with the Electrodynamc Wheel

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General Experimental Setup

Force gauges to measure lift and propulsion

Conductive plate

Electrodynaminc wheel
Exp. 1:
High-Density, Externally Driven Electromagnetic Wheel

Exp. 2:
Low-Density Self-Driven Electromagnetic Wheel
The Conductors
Halbach Field Cancellation

Fields above the array (shown in orange) are in opposite directions and cancel.

Fields below the array (shown in green) are in the same direction and augment each other.

Drawing adapted from original drawing by J.C. Mallinson (1973).
FEMM calculation of the magnetic fields produced by the circular Halbach Array. Note, the field in the center is virtually completely cancelled.
Theory 1

Induced voltage $\varepsilon$ and current $I$ in each circuit of inductance $L$ and resistance $R$ from variable magnetic flux of amplitude $\Phi_0$ resulting from relative motion of plate w/r to magnet, with velocity $v$ - are related by the circuit equation:

$$\varepsilon = L \frac{dI}{dt} + RI = \omega \Phi_0 \cos \omega t,$$

where $\omega = (2\pi/\lambda)v$, $\lambda$ is the space period of the magnet. Solving explicitly for $I$ and using the general magnetic force formula $\mathbf{F} = \mathbf{I} \times \mathbf{B}$, $\mathbf{B}$ being the field of the magnet, we can find components of the force acting on magnet. Original calculation was done for linear motion, here we compare it with circular motion of large radius.
Theory 2

Drag: \( F_x = \frac{B_0^2 w^2}{2 k L} \ast \frac{R}{\omega L} \ast e^{-2k y} \)

Lift: \( F_y = \frac{B_0^2 w^2}{2 k L} \ast \frac{1}{1 + \left( \frac{R}{\omega L} \right)^2} \ast e^{-2k y} \)

\[
\frac{Lift}{Drag} = \frac{\omega L}{R} = \frac{2 \cdot \pi \cdot v}{\lambda} \cdot \frac{L}{R}
\]

\( \lambda \) = wavelength of the Halbach array; \( k = \frac{2 \pi}{\lambda} \)

\( R \) = resistance in each closed circuit

\( v = \Omega \cdot r \), \( r \) is the radius of the wheel; \( \omega = \frac{2 \pi v}{\lambda} = \frac{2 \pi r}{\lambda} = N \Omega \)

\( L \) = circuit inductance (self-inductance + inductive coupling)

\( B_0 \) = peak field strength of the Halbach array

\( w \) = width of the inductor

\( \Omega \) = angular velocity of wheel

\( y \) = distance between the lower surface of the Halbach and the geometric center of the inductors.
Solving for current I and then using the force between the circuit and magnet’s field given by $F = I \times B$, one obtains for the ratio of the force components:

$$\frac{F(\text{lift})}{F(\text{drag})} = \left(\frac{L}{R}\right) \omega,$$

for large $\omega$

$$Y = m \ X$$

$$\omega = \frac{(2\pi/\lambda)v}$$

$\lambda$ is the space period of the magnet

For our wheel, 12 Nd magnets produces 3 full North to South oscillations per revolution

$$\omega = 3\Omega$$
Lift and Drag Aluminum

- Large Wheel Aluminum Disc
  - Equation: $y = 0.000418x + 0.135316$
  - $R^2 = 0.995791$

- Small Wheel Aluminum Disc
  - Equation: $y = 0.000090x + 0.124966$
  - $R^2 = 0.943621$

- Large Wheel Aluminum Rectangle
  - Equation: $y = 0.000295x + 0.103457$
  - $R^2 = 0.993523$

- Small Wheel Aluminum Rectangle
  - Equation: $y = 0.000319x + 0.021351$
  - $R^2 = 0.995629$

- Large Wheel Aluminum Split Guideway
  - Equation: $y = 0.000090x + 0.124966$
  - $R^2 = 0.943621$

- Small Wheel Aluminum Split Guideway
  - Equation: $y = 0.000199x - 0.008149$
  - $R^2 = 0.984739$
Lift and Drag Copper

Large Wheel Copper Rectangle

\[ y = 0.000530x + 0.111922 \]
\[ R^2 = 0.988039 \]

Small Wheel Copper Rectangle

\[ y = 0.000502x - 0.012589 \]
\[ R^2 = 0.999154 \]

Large Wheel Copper Split Guideway

\[ y = 0.000287x + 0.060601 \]
\[ R^2 = 0.983853 \]

Small Wheel Copper Split Guideway

\[ y = 0.000216x + 0.008907 \]
\[ R^2 = 0.974625 \]
Lift and (Lift / Drag) Ratio at 250 Rad/sec

- Large Wheel Copper Rectangle
- Large Wheel Aluminum Disc
- Large Wheel Aluminum Rectangle
- Small Wheel Copper Rectangle
- Small Wheel Aluminum Disc
- Small Wheel Aluminum Rectangle
- Large Wheel Copper Split Guideway
- Large Wheel Aluminum Split Guideway
- Small Wheel Copper Split Guideway
- Small Wheel Aluminum Split Guideway

Legend:
- Lift/Drag
- Lift (Newtons)
Higher RPM and Lift-Off

Small Wheel Aluminum Disc

Small Wheel Copper Rectangle
Analysis

- We compared the efficiency of the lift to drag ratio on the metal plate on when both the wheels spinning with 250 radians per second and we saw that the aluminum disc was more efficient at producing lift than the aluminum rectangular plate.
- We saw that the Aluminum Split and the Copper split metal plates were both inefficient in producing lift. Explanation: the split has broken (interfered with) the eddy currents responsible for the lift.
- The larger wheel is more efficient than the smaller wheel at the same angular velocity $\omega$. 
Conclusions

• Our Experiment, generally, supported theoretical prediction
  – The larger the inductors (larger circular disc vs. rectangular plate), the slower a speed was needed to reach the point where lift overtook drag.
  – The closer the wheel of magnets was to being a straight line (the larger the radius), the higher the lift to drag ratio at the compared angular velocity $\omega$ of 250 radians / sec.
Applications

• Maglev Cargo and/or Passenger Vehicles
• Non-contact gear coupling
• Non-contact conveyor belts based on EDW
• Liquid metal pumps
• Projectile launchers
References


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