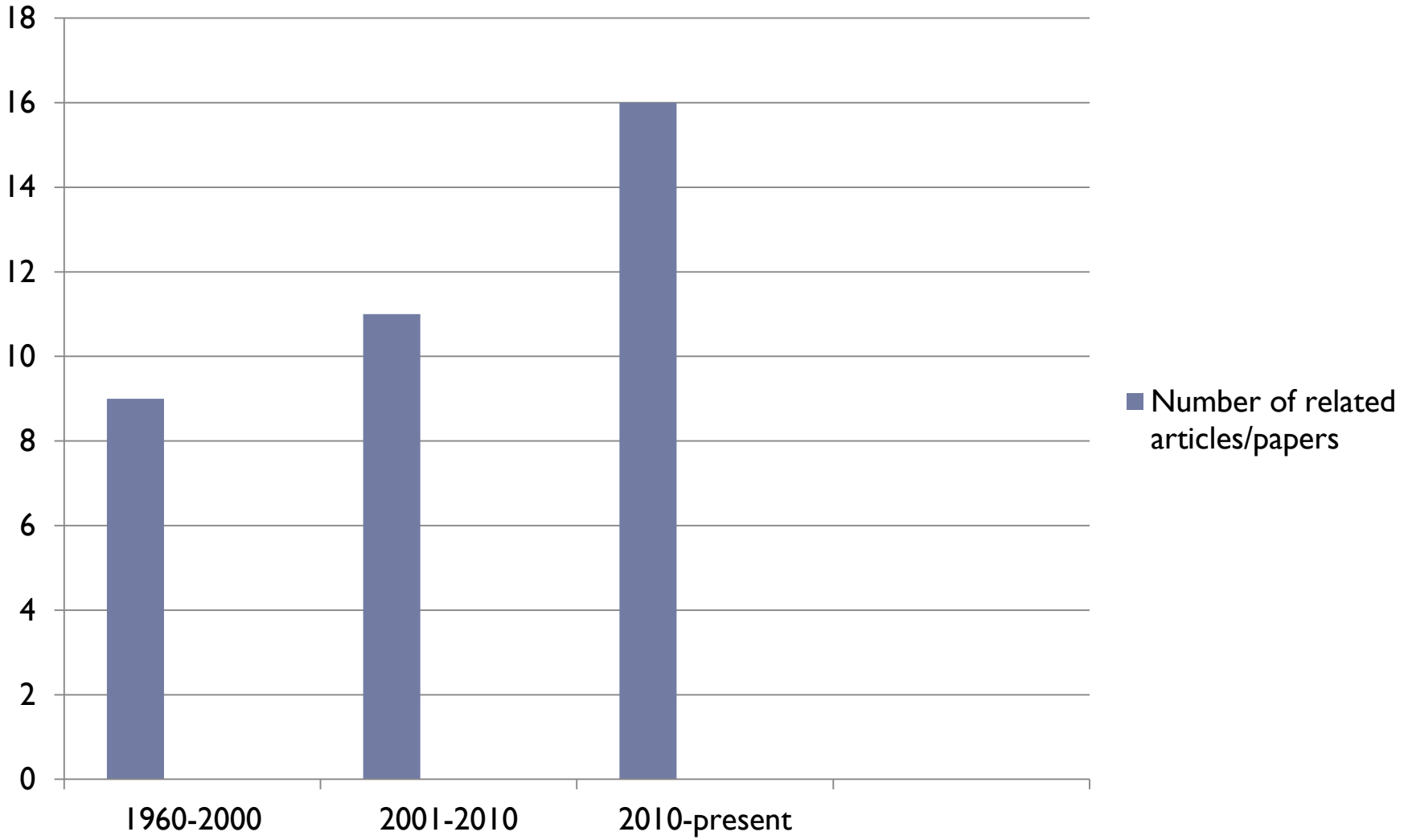
ORTA DOĞU TEKNİK ÜNİVERSİTESİ
MIDDLE EAST TECHNICAL UNIVERSITY

Linear Permanent Magnet Machines

Aydın BAŞKAYA – 11 May 2015

Researches about the topic



Outline

1) History
2) Principles of Operation
3) Application areas & examples
4) Advantages & Disadvantages
5) Conclusions
6) References

1) History

- An early example built by Wheatstone in 1841, was too inefficient to be practical
- First feasible linear induction motor is described in the US patent by Alfred Zehden in 1905.
- Hermann Kemper built a working model in 1935.
- First full-sized working model was developed by Dr. Eric Laithwaite in the late 1940s.
- Halbach effect was discovered by John C. Mallinson in 1973. It was founded very useful for PMs in linear machines on the following years.

2) Principles of Operation

- Laithwaite's classification

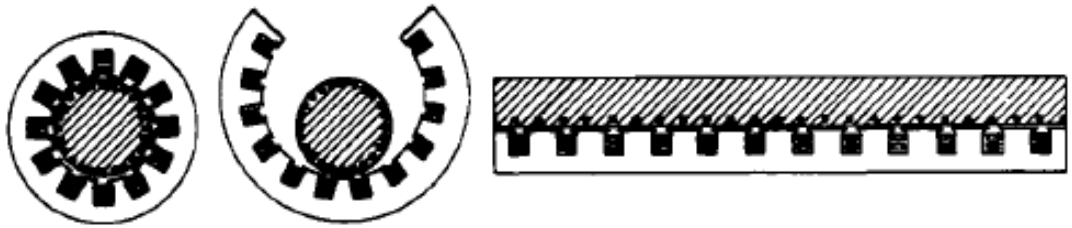
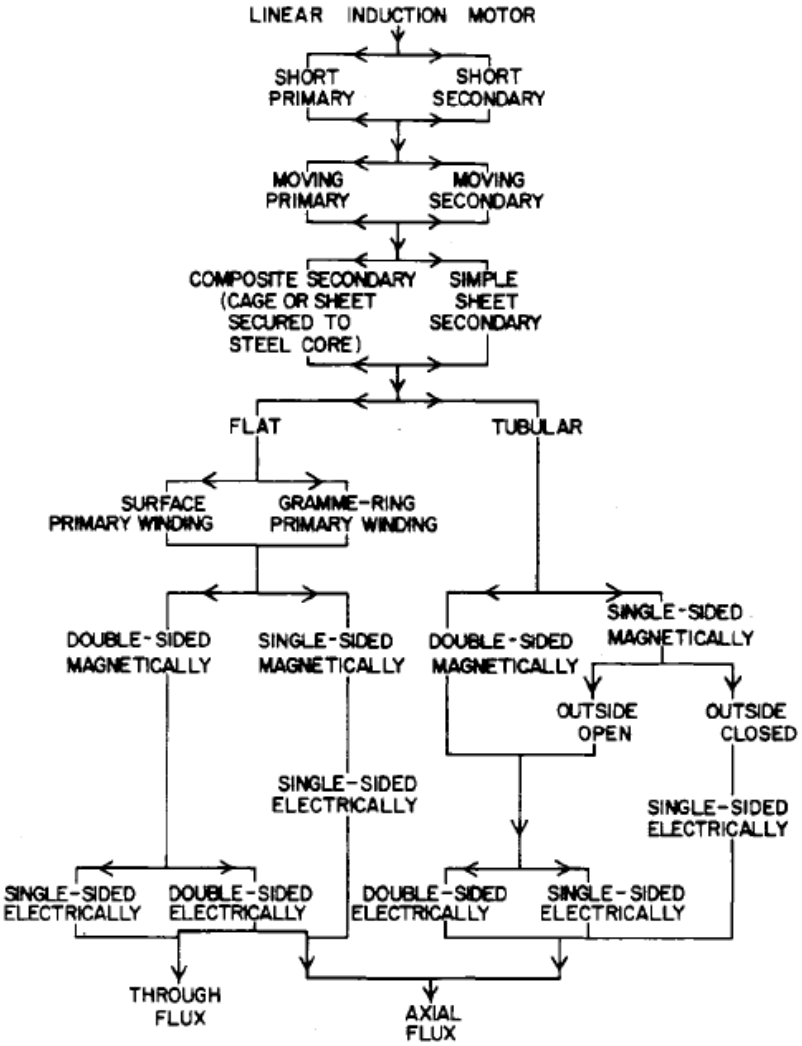


Fig. 1. Imaginary process of unrolling a conventional motor to obtain a linear induction motor.



- Linear Induction Motor (LIM)
- Linear synchronous motor(LSM)
- Both parts can move depending on the applications.

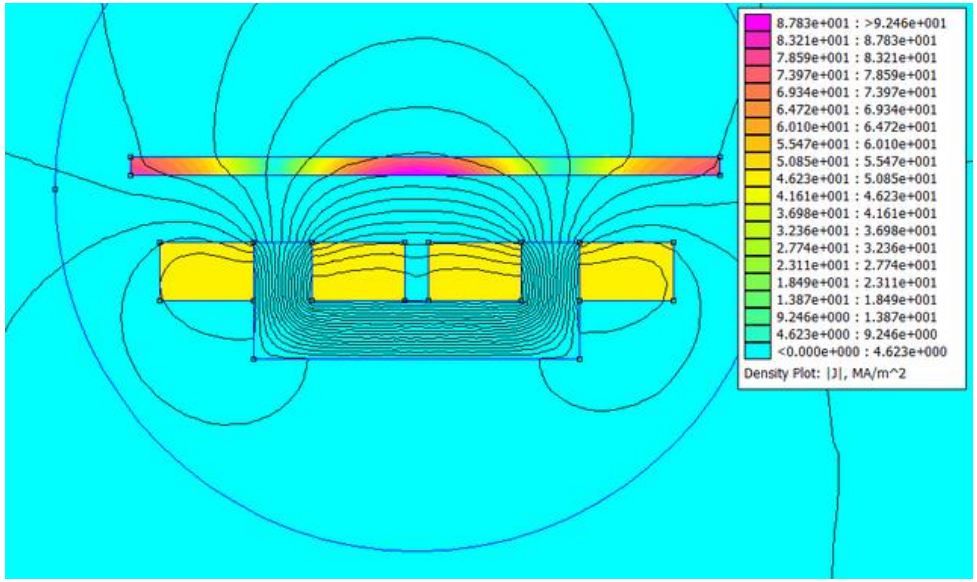
Principles of Operation

- A linear electric motor's primary typically consists of a flat magnetic core (generally laminated) with transverse slots which are often straight cut with coils laid into the slots, with each phase giving an alternating polarity and so that the different phases physically overlap.The secondary is frequently a sheet of aluminum, often with an iron backing plate.
- Push the secondary,

  levitate it,

  carry it along the axis

  by LENZ's law



Principles of Operation

- Some LIMs are double sided, with one primary either side of the secondary, and in this case no iron backing is needed.

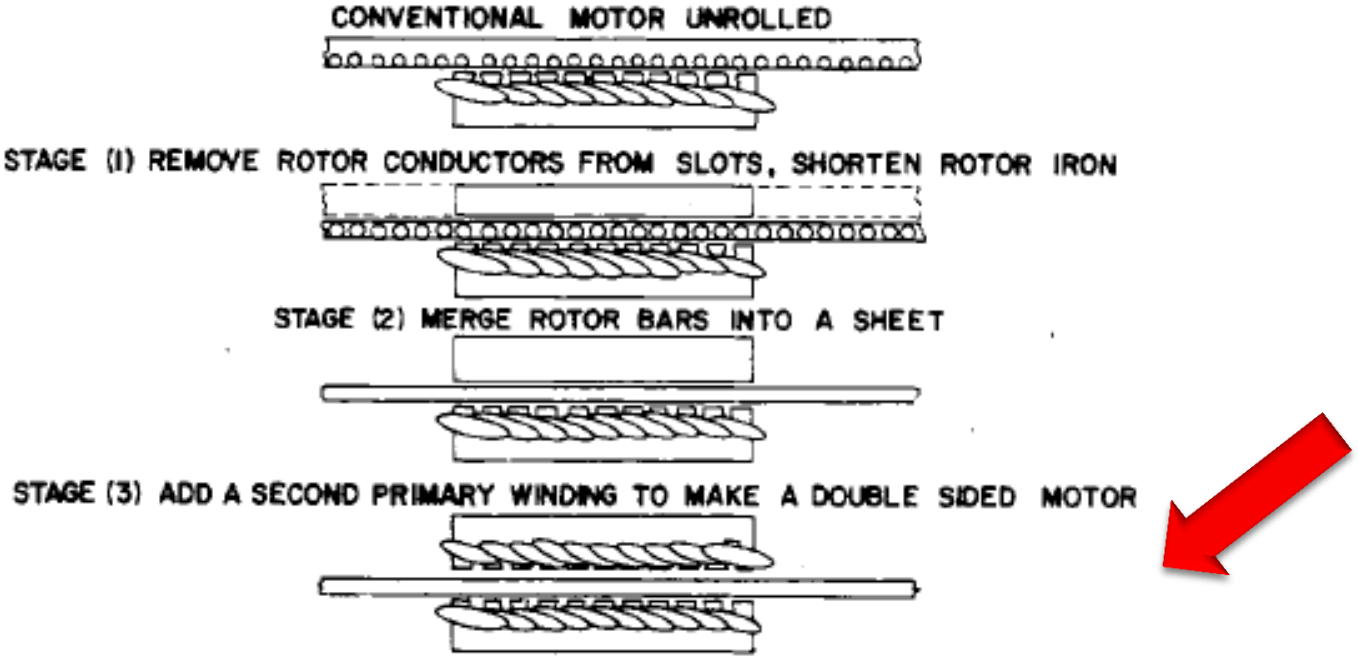


Fig. 4. Development of the "sheet-rotor" motor.

Principles of Operation

- Sometimes linear permanent magnet machines can be in a tubular shape :

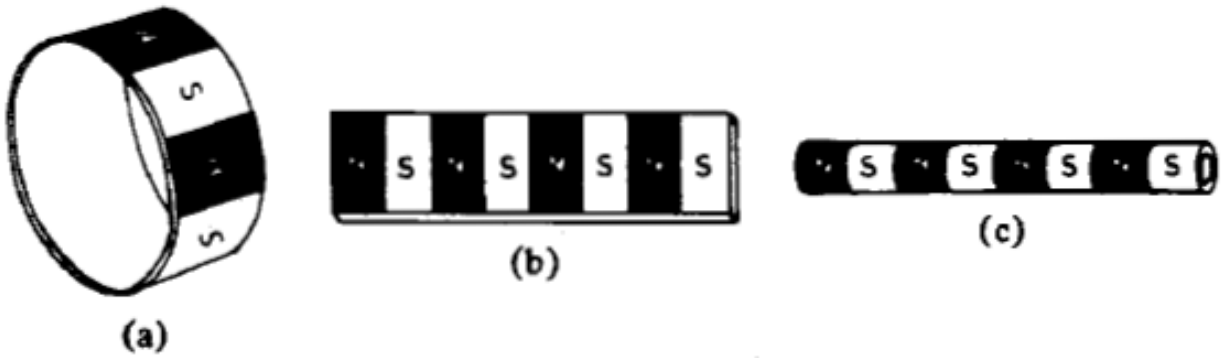
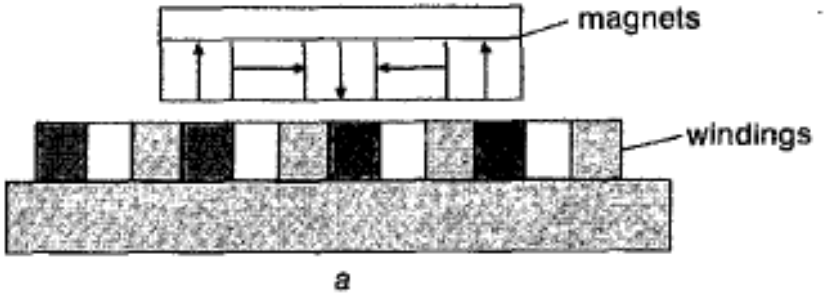


Fig. 34. (a) Conventional rotary machine. (b) Flat linear motor, which can be regarded as the intermediate class. (c) Tubular linear motor. Topological relationship between (a) and (c) is apparent here.

- Such a tubular machine has the advantage of a winding without undesirable end turns

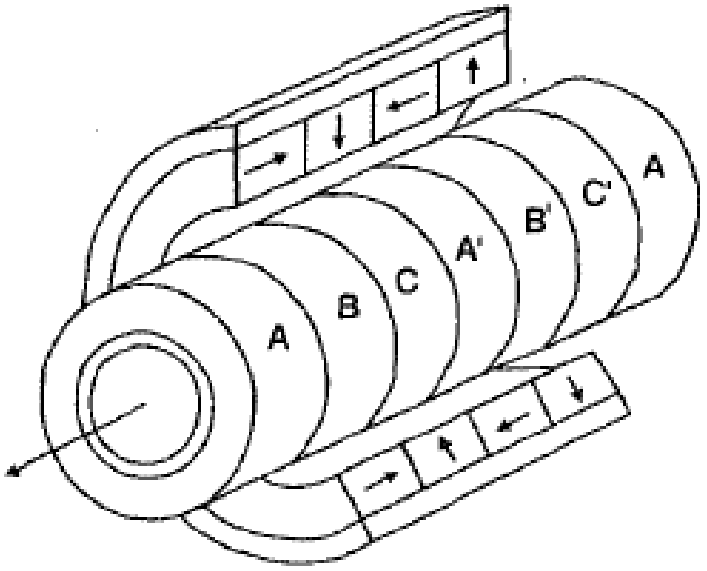
Principles of Operation

- Halbach arrays - special arrangement of PM that eliminates the magnetic field on one side of the array
- airgap field distribution- sinusoidal
- negligible cogging torque and an essentially sinusoidal emf
- No need to conventional design features such as skewing of the stator/rotor, optimisation of the magnet pole-arc, distributed stator windings, etc.



Principles of Operation

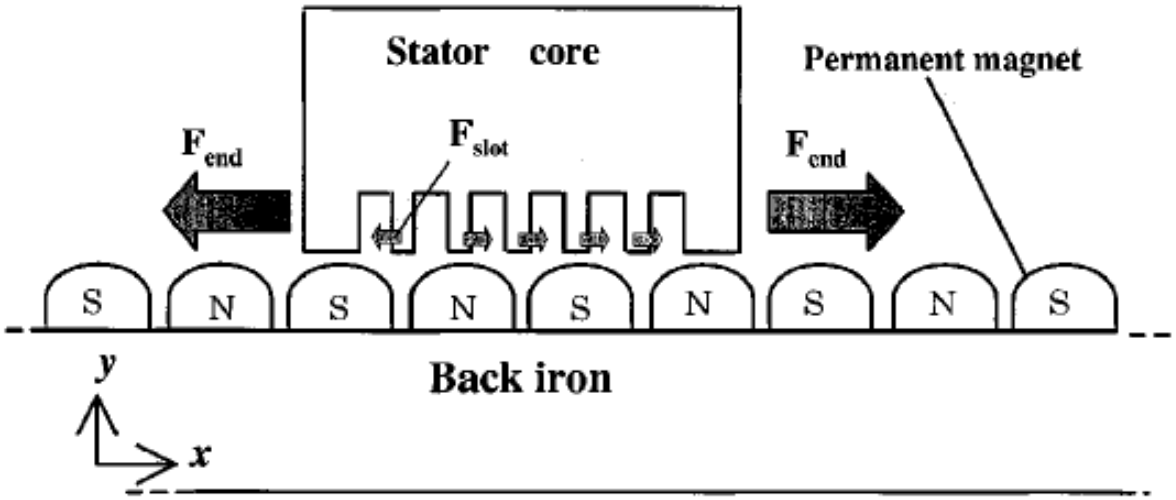
- Further, due to the self-shielding magnetization, rotor back-iron is not essential, so that the mass and inertia can be reduced, with a consequent improvement in dynamic performance



b

Principles of Operation

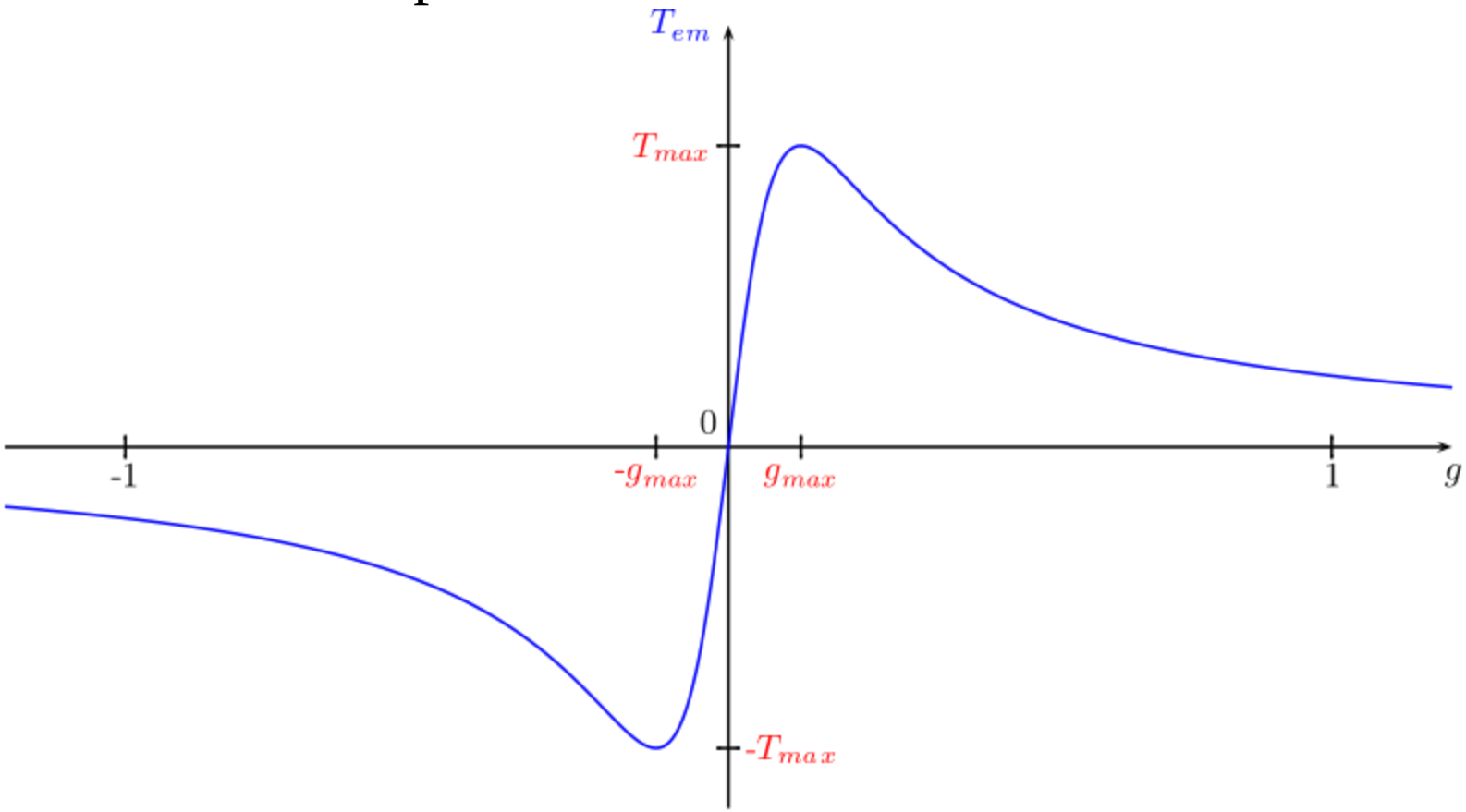
- 'End Effect' in Linear PM machines: choosing tubular one
- Detent force-developed from the magnetic attraction between the PM mounted on the rotor and the stator teeth
- Undesirable torque ripple,vibration and noise



F_{slot} is resulting form the slotting of a stator core.
F_{end} is resulting from the finite length of a stator core.

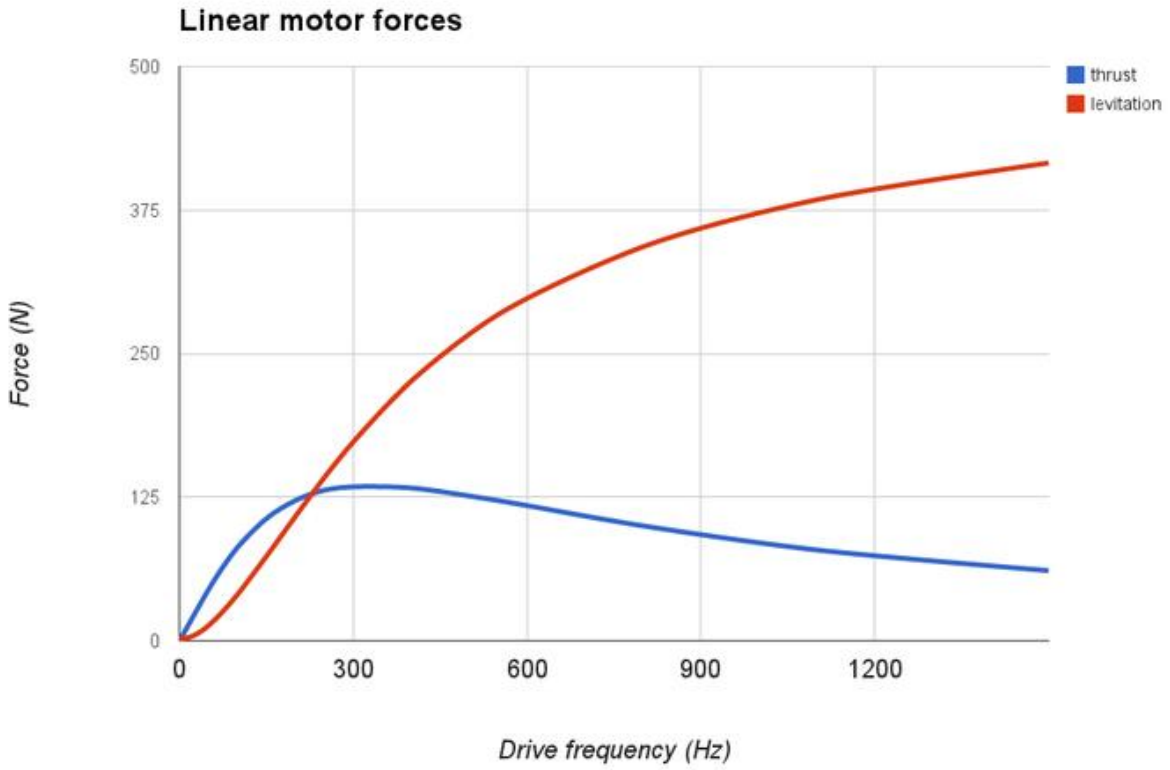
Principles of Operation

- Thrust force-slip curve



Principles of Operation

- Levitation-thrust force

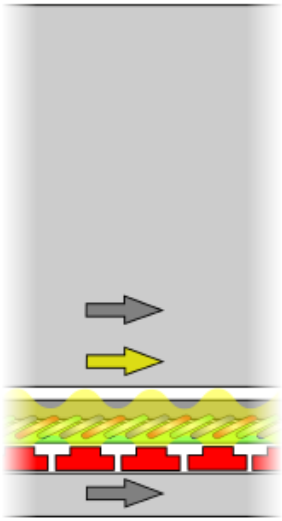


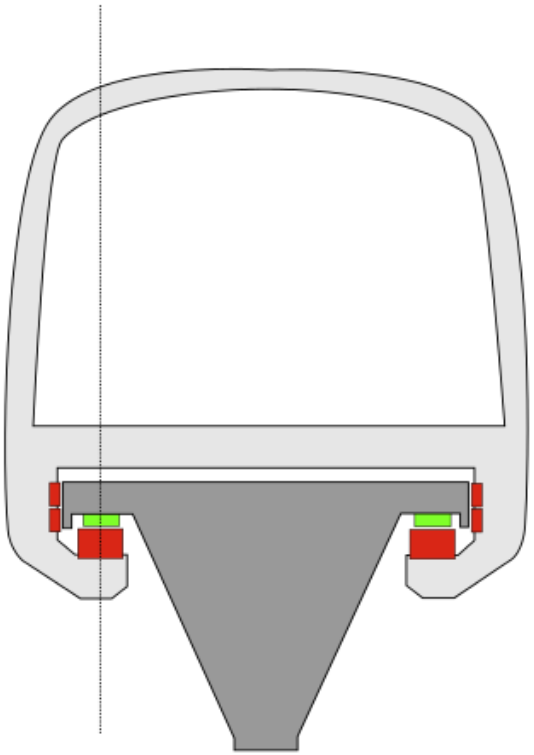
3) Application areas & examples

- Sliding doors
- Wave energy converters
- Aircraft Launch System
- Maglev trains
- Roller coasters
- Weapon: Coilgun, railgun
- Spacecraft propulsion
- Sensitive linear motion controls(sometimes 2-d control!)
- Electric vehicle engine systems

Application areas & examples

- Maglev trains : Transrapid-LSM





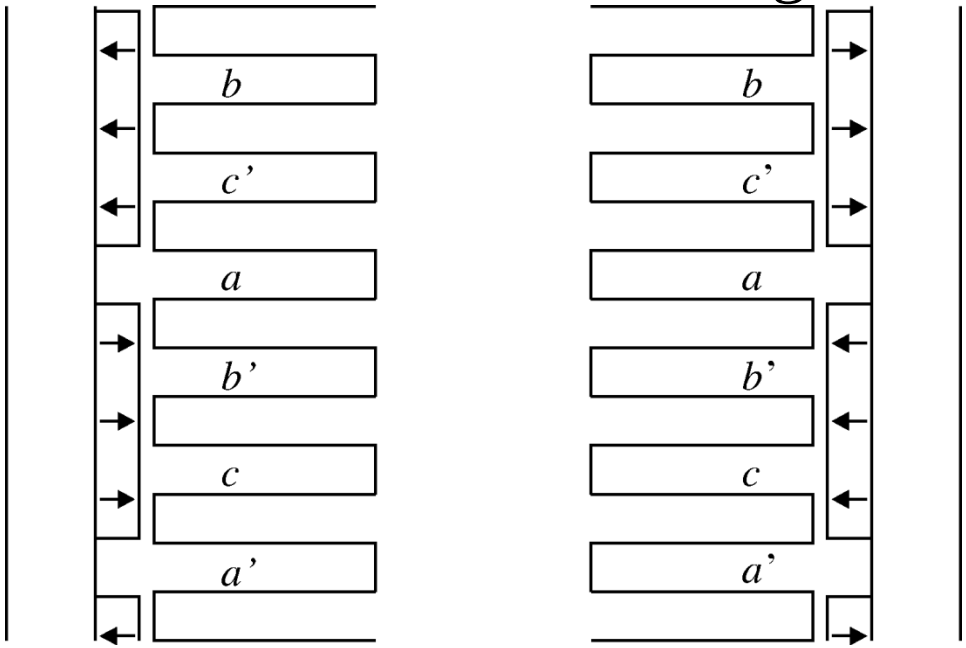
- Electromagnetic suspension (EMS)
- 476 km/h

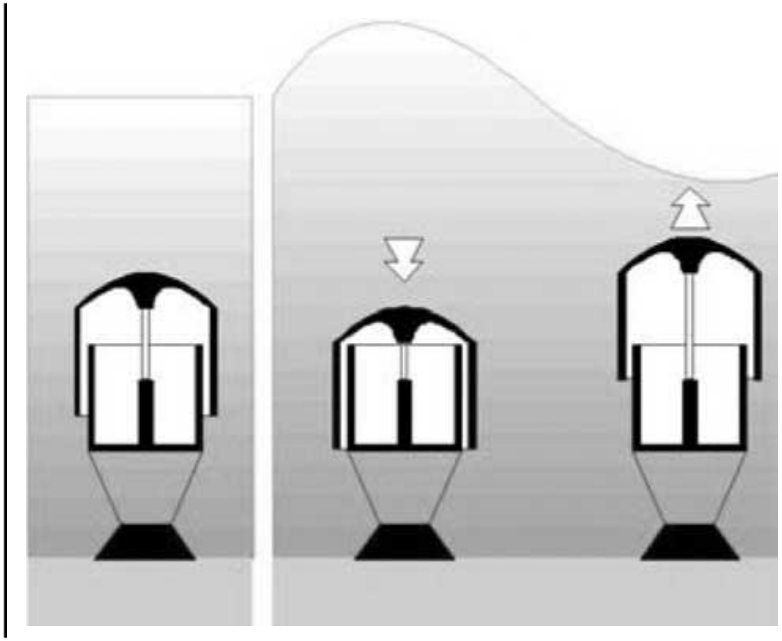
Application areas & examples

- Electromagnetic Aircraft Launch System(EMAL)-LIM
- Energy-storage subsystem draws power from the ship and stores energy (up to 484 MJ) kinetically on rotors of four disk alternators, and then releases that energy in 2–3 sec. Each rotor can store 121 megajoules at 6400 rpm, and can be recharged within 45 seconds of a launch

Application areas & examples

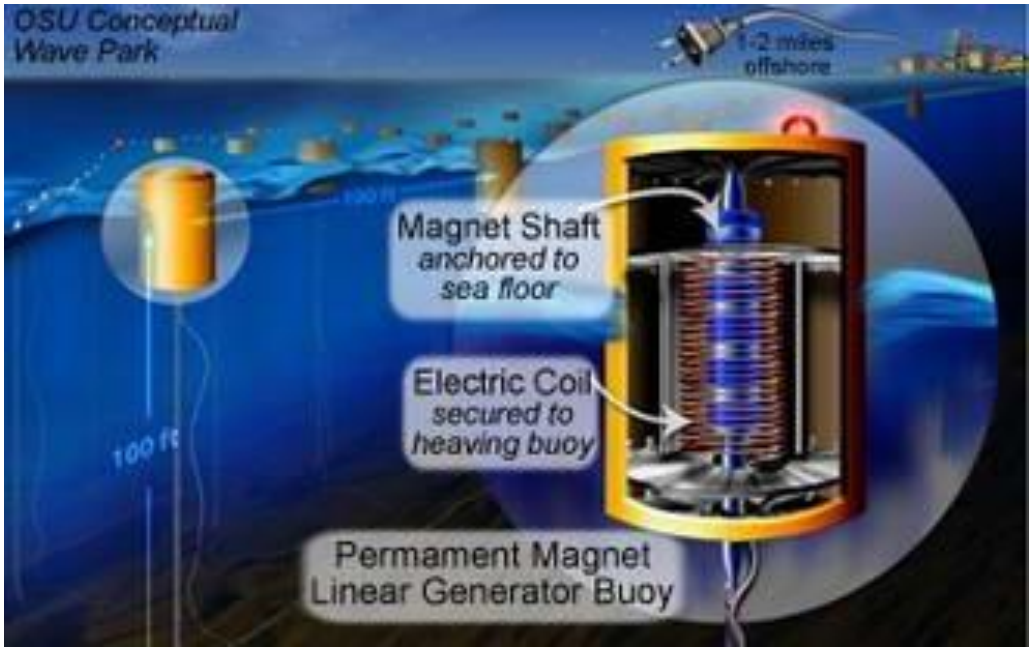
- Wave-energy converters: 1MW(Average power)
- Converting the linear floater motion into rotating motion and use a rotating generator-extremely difficult to build a robust, maintenance-free gear.





Application areas & examples

- When waves cause the coil to move up and down relative to the fixed magnetic shaft, voltage is induced and electricity is generated. Each buoy could potentially produce 250 kilowatts of power.



Application areas & examples

- Free piston generator-which integrates a combustion engine and a linear electrical generator into a single unit.
- Simple structure, high efficiency and robustness,
- Suitable for application in series hybrid electric vehicles.

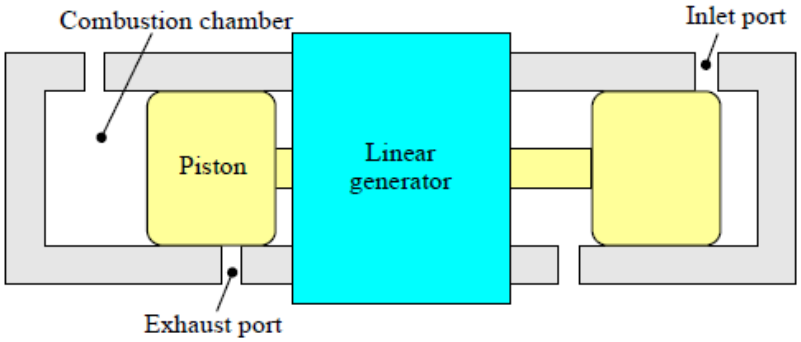


Figure 1. Schematic of a free-piston generator.

- A commercial version of this type of engine is available

4) Advantages & Disadvantages

- Advantages:

✓ Increase reliability fewer components subject to wear

✓ Acceleration and braking not dependent on friction

✓ Yields appropriate force only when linear motion is needed

✓ The absence of mechanical gears and transmission systems, which results in higher efficiency, better dynamic performance, and improved reliability.

✓ They serve to deliver high pulsed power in the short period of time

Advantages & Disadvantages

- Disadvantages:

✓ Longitudinal end effects due to finite length of stator or rotor

✓ Can require complex power electronics for control units

✓ Can require external energy storage units such as flywheels etc. in order to give high pulsating short-timed force

✓ Investments may cost too much(expensive PMs, superconducting systems etc.)

5) Conclusions

- Linear permanent magnet machines used where linear motion is needed rather than rotary one
- It can be single-sided or double-sided, short stator or short rotor, dependent on the application requirements
- Its main working principles is Lenz's rule between stator and rotor, the main reason of levitation and propulsion
- Longitudinal end effect is the biggest challenge in the area due to its inherent finite length, therefore sometimes tubular topology can be used
- Can require complex power electronics to control and position adjustment systems

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Questions?