Variable-Magnetic-Flux Motors for Opening up a World of the New Motor-Drive Technology

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Abstract:

Saving energy in electrical appliances and electric vehicles (EV) requires a reduction in power consumption of motors. The motors used in these appliances operate at variable speeds. In addition, these motors operate with small load in stationary mode and with large load in start-up mode. A permanent magnet motor can operate with high efficiency at a rated power. However, the efficiency of this motor is lower at small loads or high speeds because a large constant magnetic force leads to a significant core loss. Also, the flux-weakening current to depress voltage at high speed leads to a significant copper loss. Hence, new technologies that control a magnetic force of a permanent magnet depending on the load or speed have been developed. A variable-magnetic-flux motor operates over a wide range of speed with high power and efficiency. This article introduces new motors which can change magnetic flux of permanent magnet.

Variable-Magnetic-Flux Motors for Crating New Generation Motor Drives

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1.Variable Speed Motor for Environmental and Energy Conservation

Society conserving energy and reducing carbon monoxide

⇩

Low power consumption systems

⇩

Highly efficient energy converse systems for the total drive range

Motor drive performance

[High efficiency logic]
Universal Wide-range speed variability Wide range speed variability and continuous operation
（Rated）Point ⇨ Face ⇨ Face × Time

HEV citations：Ford homepage

EV citations：VW homepage

Railway citations: JR East homepage

Induced Voltage of Permanent Magnets for Variable Speed Drives

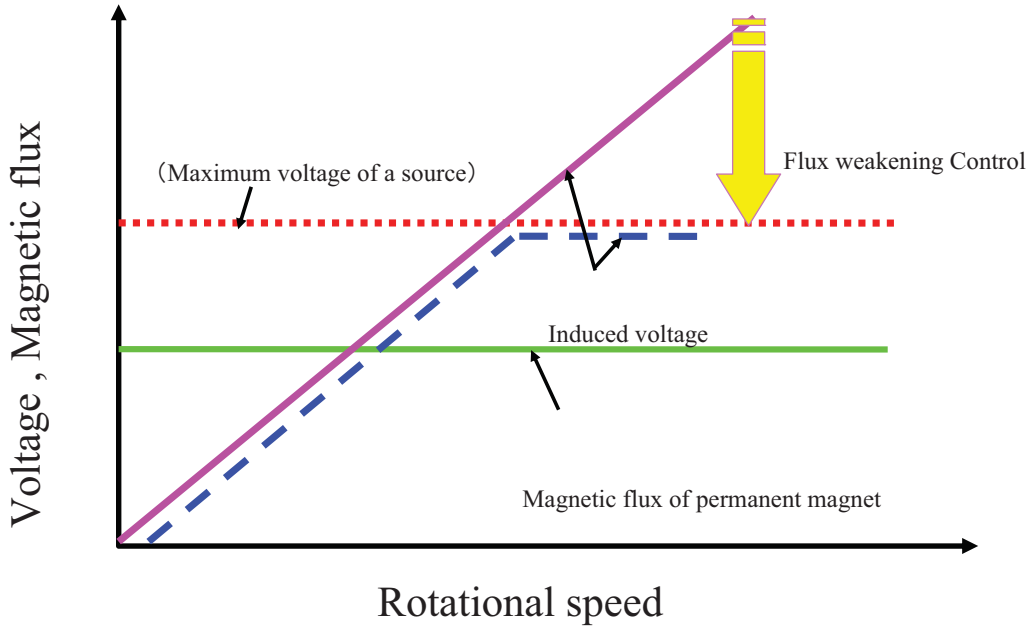


Fig. 1. Voltage regulation at variable-speed using flux-weakening control for a conventional permanent magnet motor.

Loss Reduction and Variable Flux of Flux Weakening Control

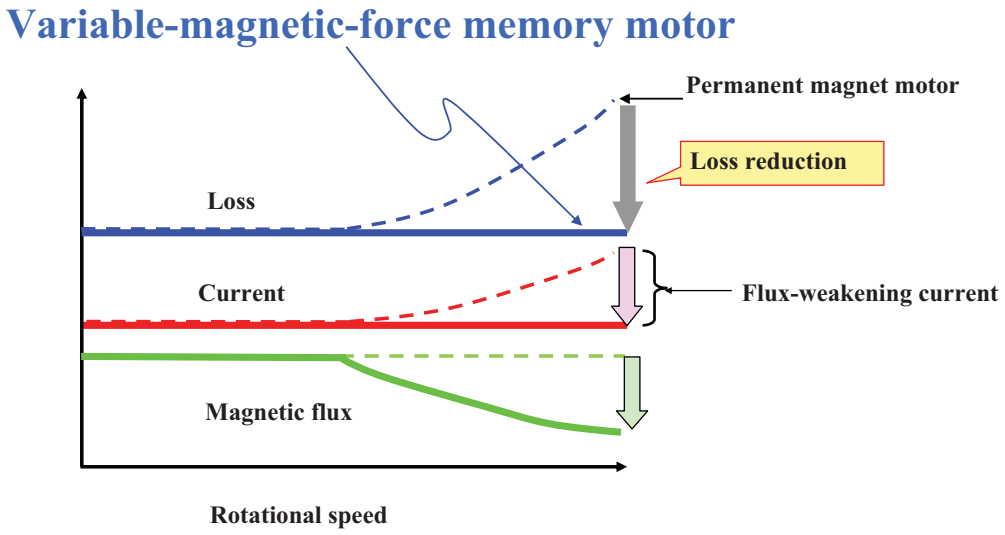


Fig. 2. Loss at variable speed drive.

2. Adjusting Variable Flux and Induced Voltage

Regulation of induced voltage by changing the magnetic flux

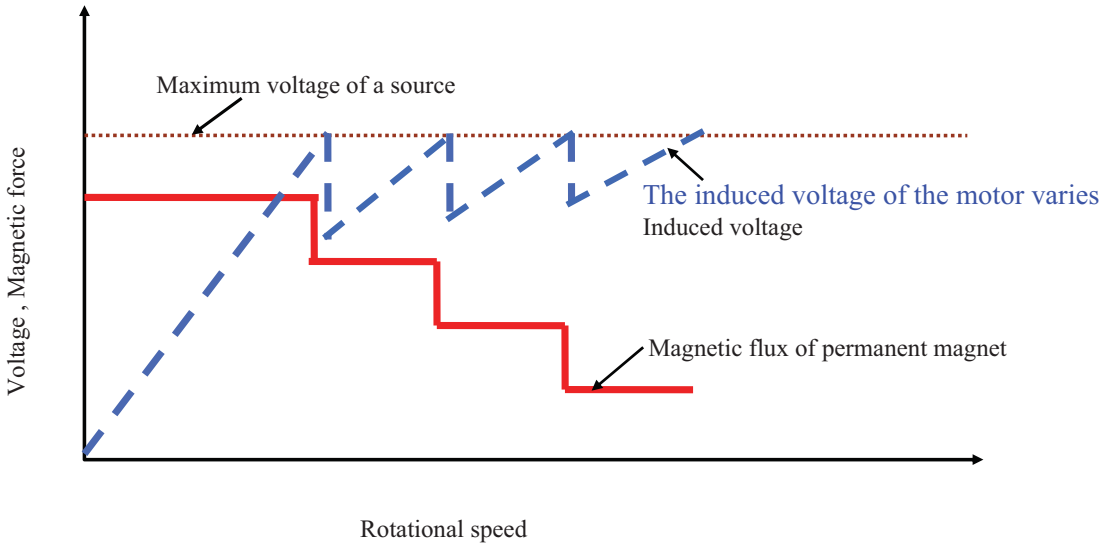
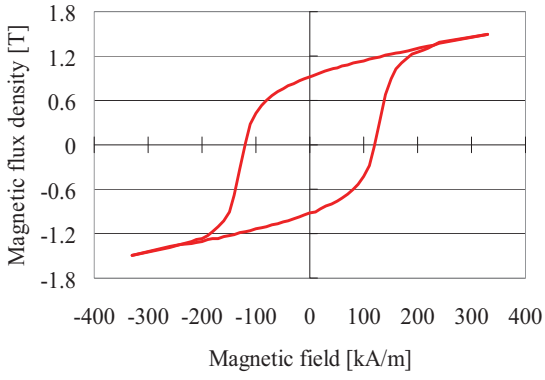


Fig. 3. Voltage regulation at variable-speed by changing magnetic flux.

Variable magnetic force

Variable Magnetization of Permanent Magnets

Motors for high torque and wide speed range applications



B-H curve of permanent magnets

characteristics of permanent magnets

Fig. 4. B-H curve of a permanent magnet.

3. Motor Structure to Vary the Magnetization of Magnets

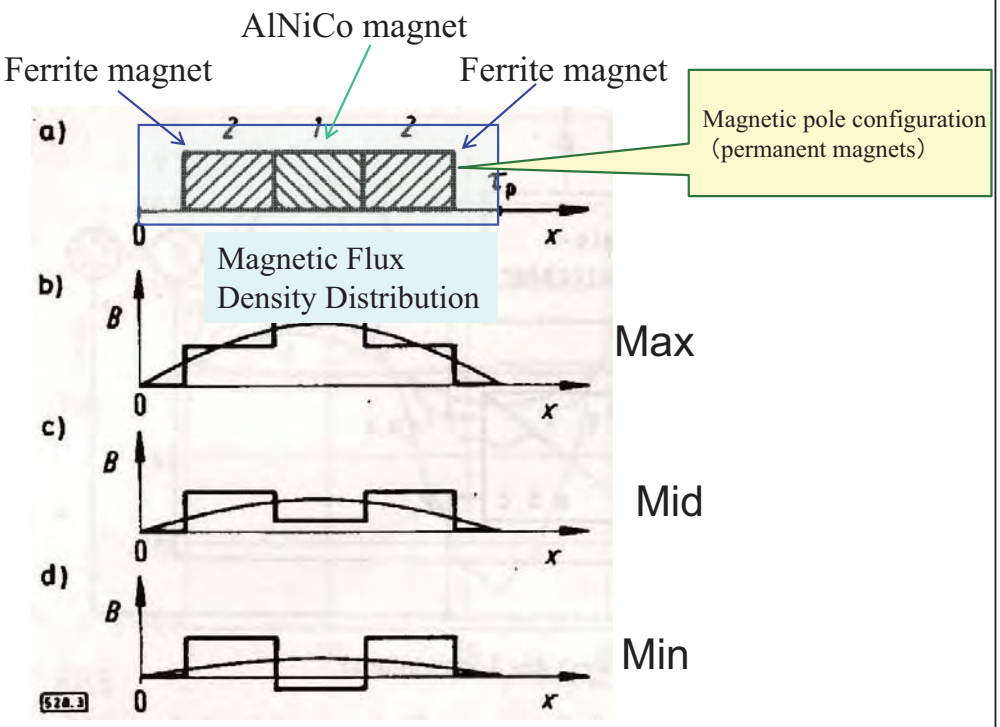


Fig. 5. Change of magnetic flux density.

Reference
[1]

Memory motor

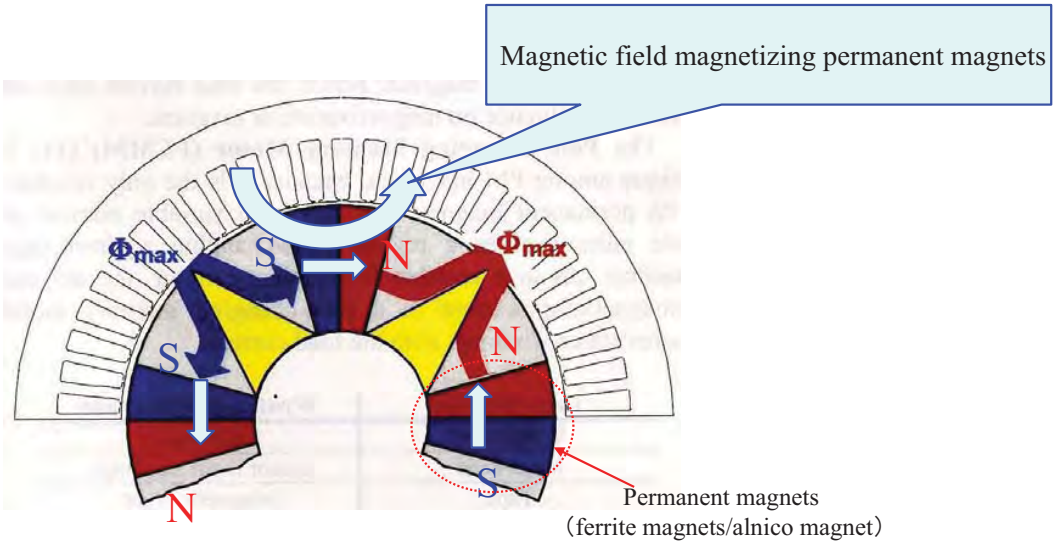


Fig. 6. Memory motor.

Reference [2]

4. Variable Magnetic Flux Motors Based on New Principles

Motors reversing the constant magnetic force concepts of permanent magnets

World's first technology Reference [3], [4], [5]
Motor drive systems based on new concepts for freely varying electromagnetic force of permanent magnets similar to electromagnets

Commercialized in laundry machines from Toshiba in October, 2009

Permanent magnetic properties required by variable magnetic force

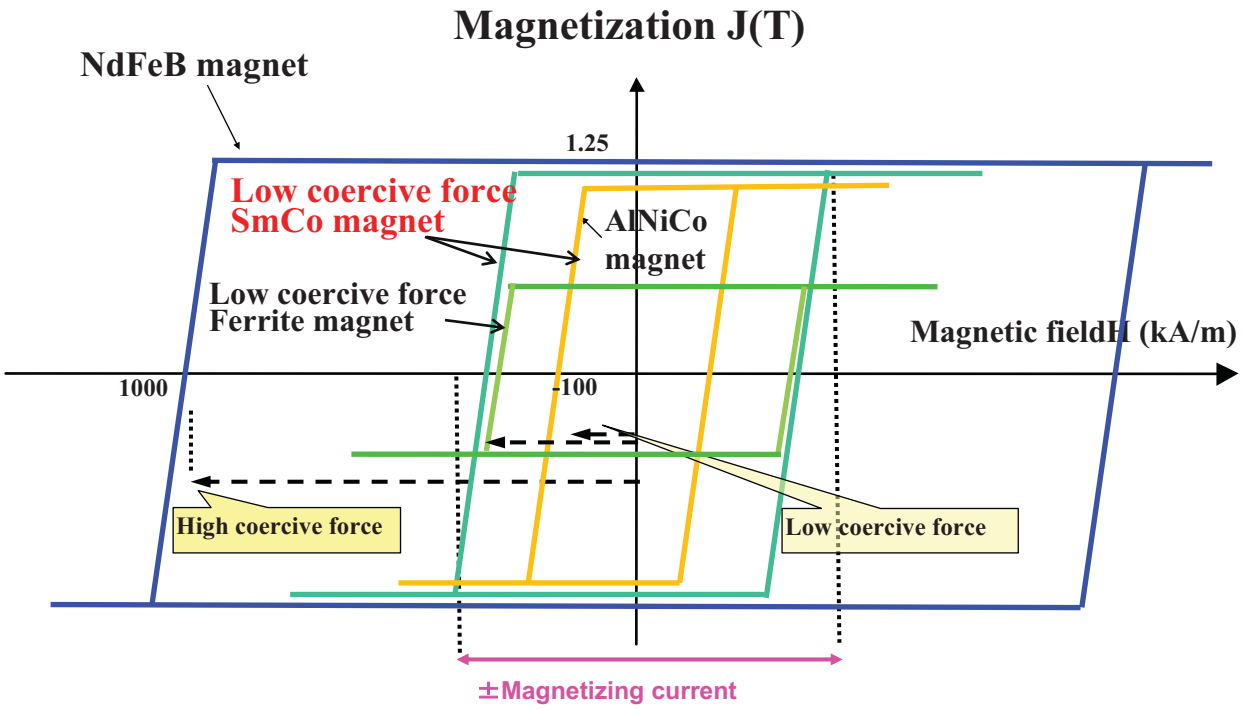


Fig. 7. Magnetic property of permanent magnet for variable-magnetic force.

Basic Magnetic Structure for Variable Magnetic Force (Magnetic Poles)

Variable magnetized magnet (Low coercive force)

Constant magnetized magnet (High coercive force)

Variable magnetized magnet (Low coercive force)

Constant magnetized magnet (High coercive force)

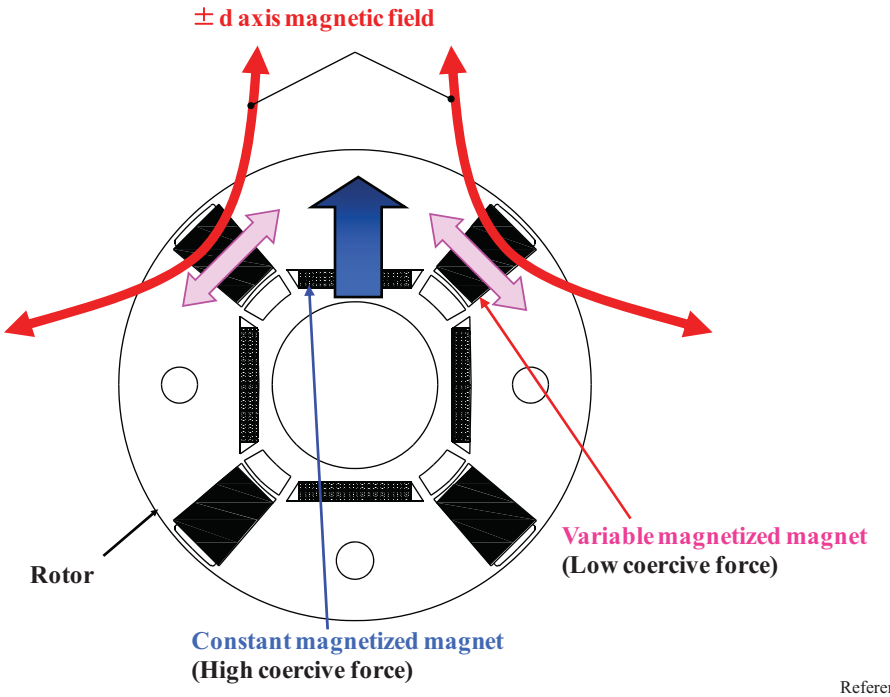
(a) Series magnetic circuit type

(b) Parallel magnetic circuit type

Fig. 8. Basic configuration of the variable-magnetic-force memory motor.

Reference [3], [4], [5]

Principle Model and Mechanisms of Variable Magnetic Flux Motors



Reference [3], [4], [5]

Fig. 9. Configuration of the variable-magnetic-force memory motor.

Varying Operating Points of Magnets for Variable Magnetic Force

Magnetic hysteresis curve

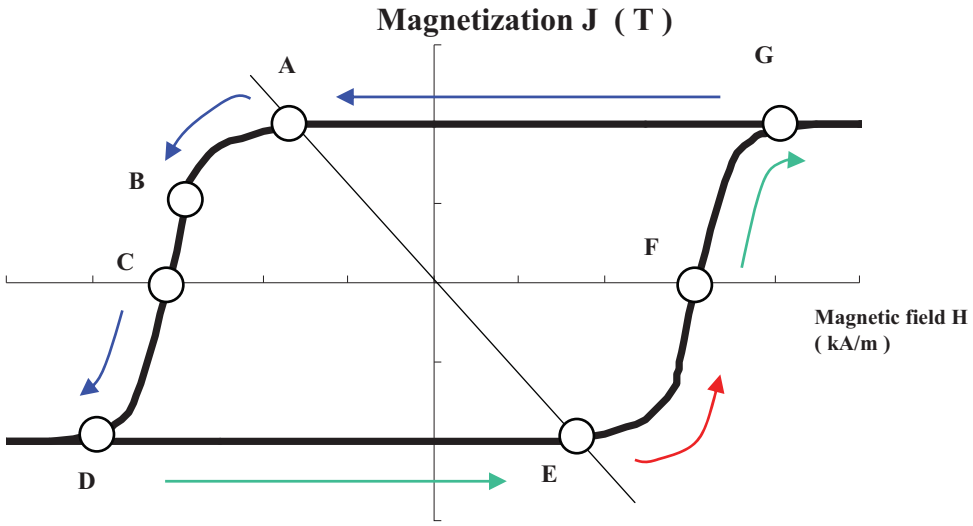


Fig.10. Change of operating point for the variable magnetized magnet.

Variations of Flux Leakage Distribution Caused by Permanent Magnets

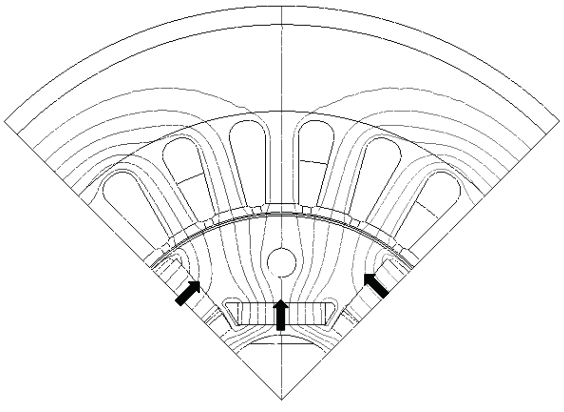


Fig. 11. Magnetic flux distribution at maximum magnetic flux linkage.

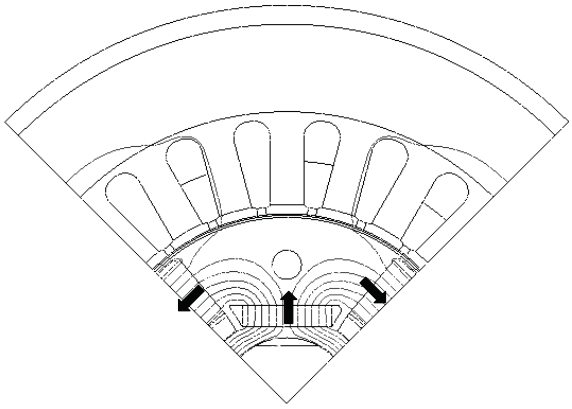


Fig. 12. Magnetic flux distribution at minimum magnetic flux linkage.

Reference [3],[4],[5]

Variations of air-gap magnetic flux

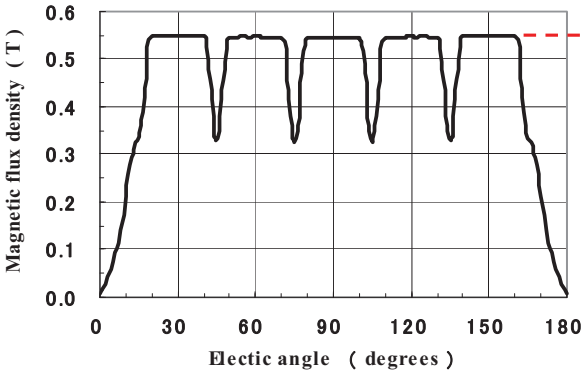


Fig. 13. Distribution of Air-gap magnetic flux density at maximum magnetic-force.

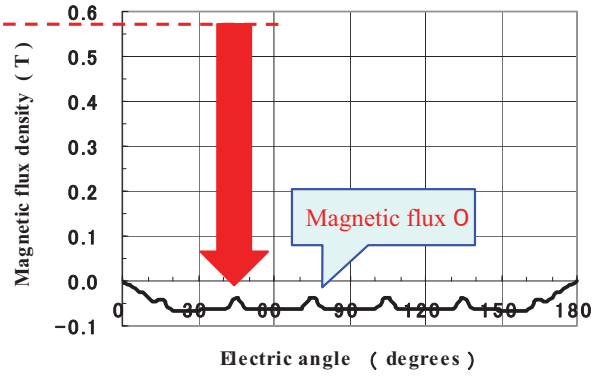


Fig. 14. Distribution of Air-gap magnetic flux density at minimum magnetic-force.

Reference [3], [4], [5]

Rotor of principle model for verification

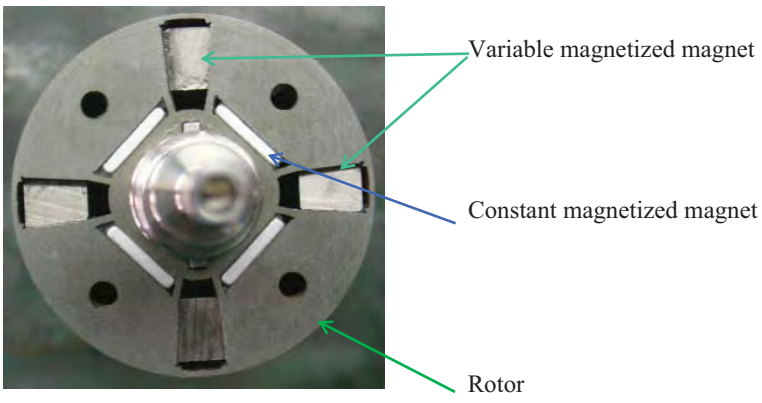
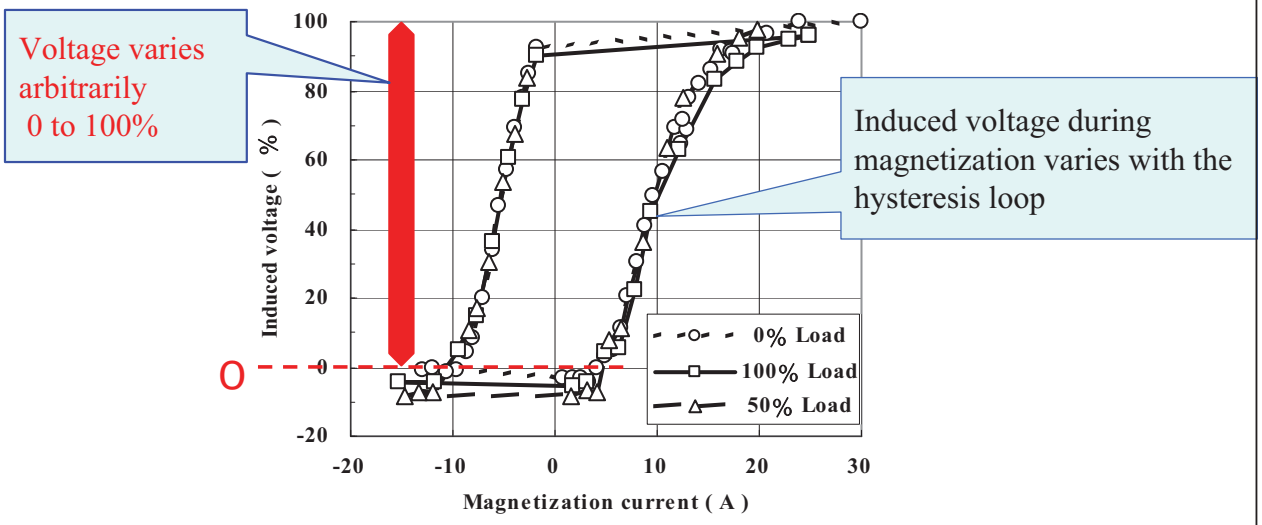


Fig. 15. Principle model for verification.

Reference [3], [4], [5]

Induced voltage and magnetization current characteristics



Magnetization characteristics of magnets in motors

Fig. 16. Magnetization characteristics.

Reference [3], [4], [5]

Induced voltage and magnetization current (minor loop)

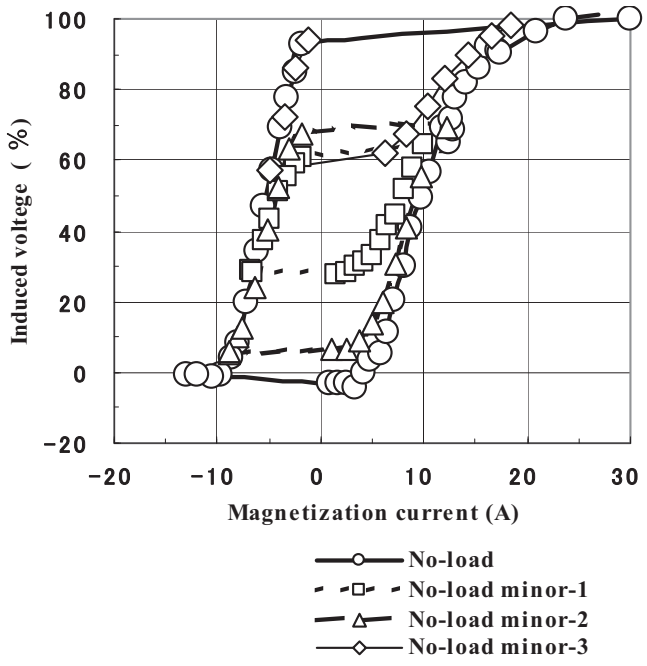


Fig. 17. Minor loop characteristics of magnetization.

Reference [3], [4], [5]

Magnetic Flux Variations of Magnets Caused by Pulse Magnetization Currents

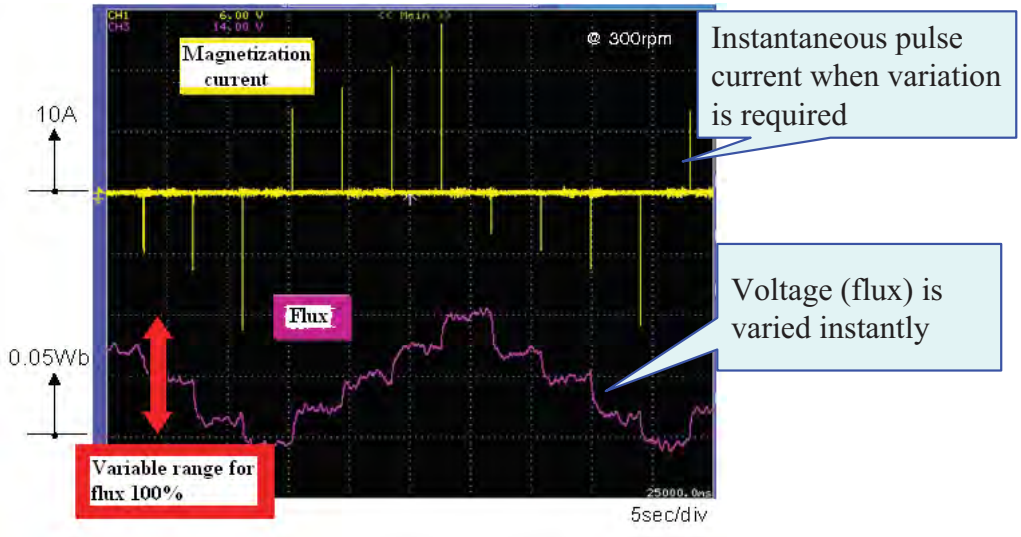


Fig.18 Change of induced voltage.

Reference [3], [4], [5]

Magnet properties and variable magnetic force

Producing reluctance torque

Negative d-axis current is required

Back EMF is used to vary magnetic force of magnets

Coercive force sustanted by negative d-axis current

Coercive force sustanted by negative d-axis current

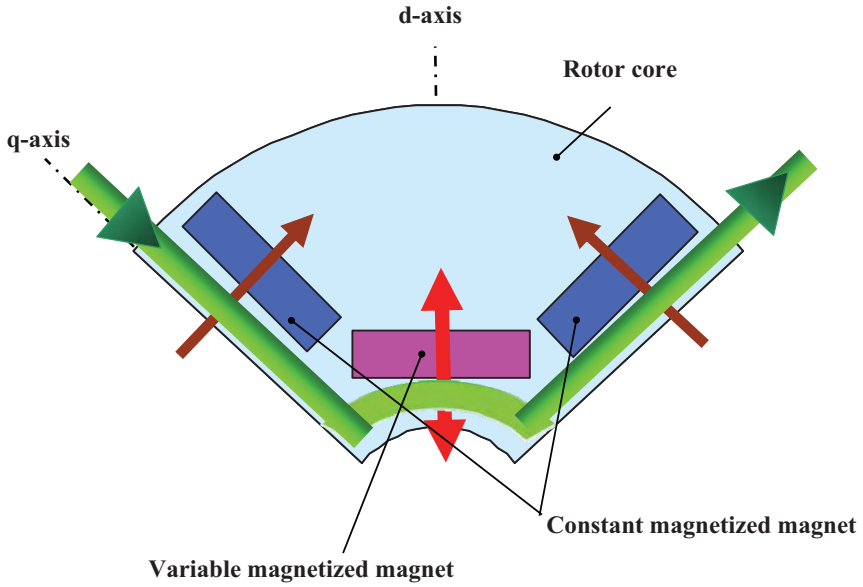
Variable magnetization

Both

- Magnetic Structure Concentrating the Magnetization Field for Variable Magnetic Force of Magnets
- Features concentrating the magnetic field

Variable Magnetic Flux Motors that Combine Reluctance Torque

Structure using both the reluctance torque that is produced and the variable magnetic flux



Reference [6]

Fig. 19. Configuration of a variable-magnetic-force motor with reluctance torque.

Variable Magnetic Flux Motors that Combine Reluctance Torque

Structure using both the reluctance torque that is produced and the variable magnetic flux

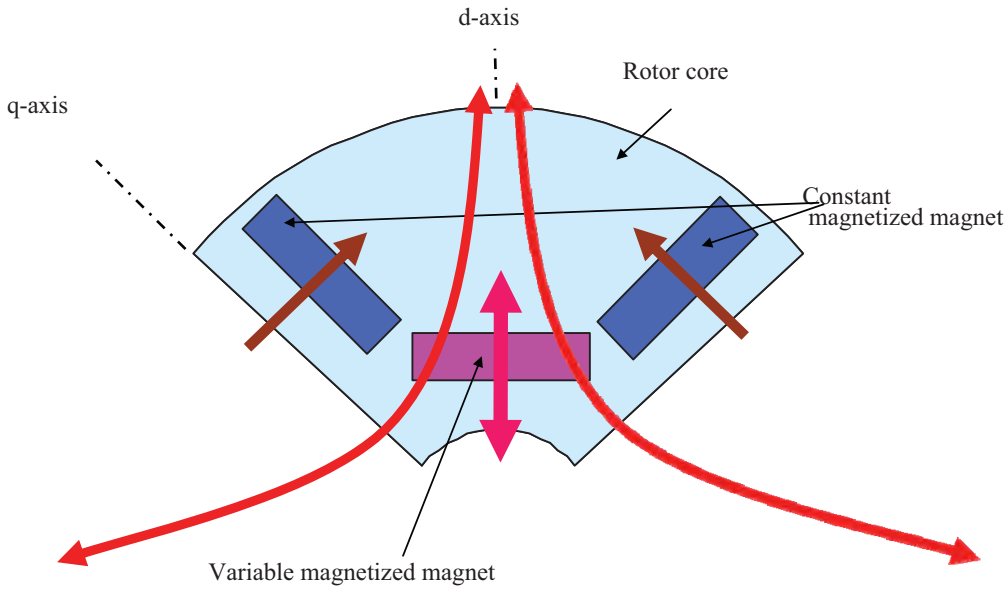


Fig. 20. D-axis flux

Reference [6]

Torque versus current phase characteristics

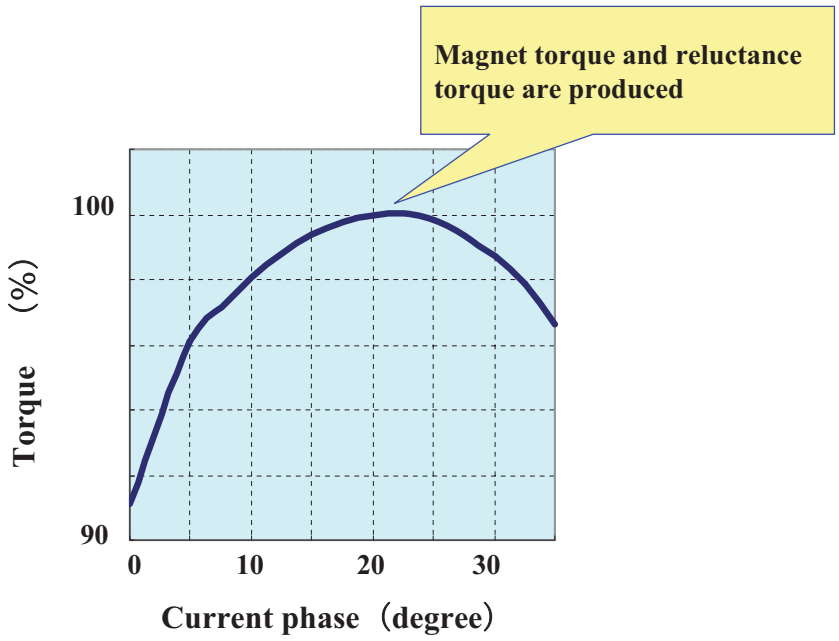
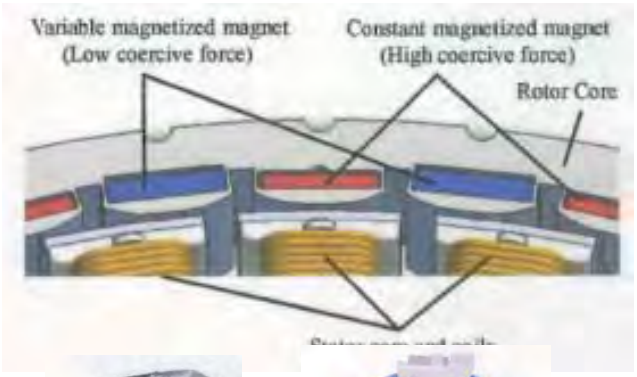


Fig. 21. Torque characteristics

Reference [6]

Applications in Appliances

World's first laundry machine using a variable magnetic flux motor



TOSHIBA ZABOON

Required characteristics: Two contradictory characteristics
Washing mode: Low speed high torque Draining mode: High speed low torque

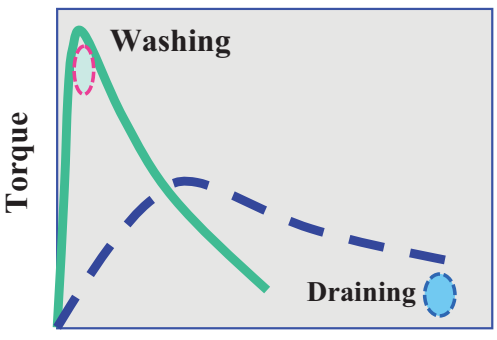
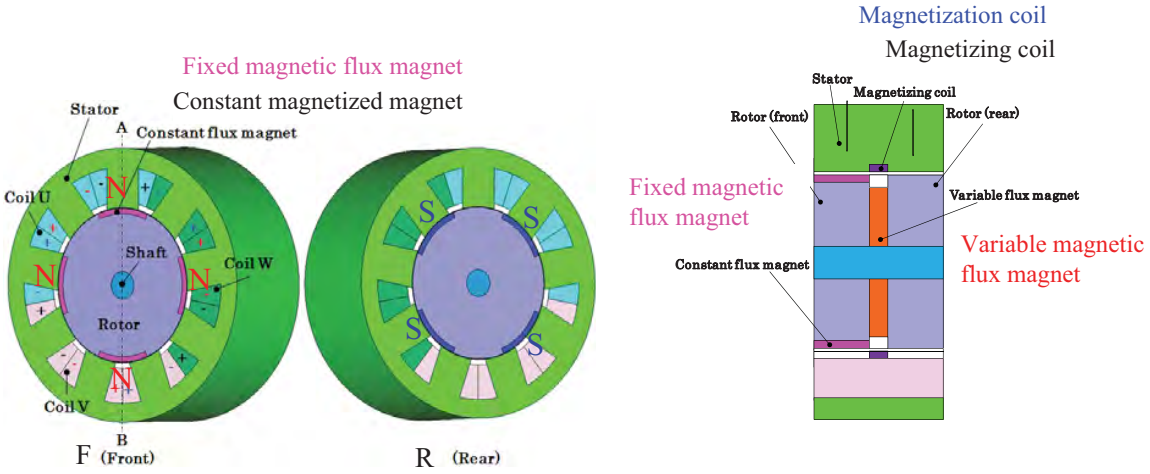


Fig. 22. Washing machine with a variable-magnetic force motor.

Reference [7]

5.Basic Structure of Hybrid Variable Magnetic Flux Motors

Magnetic flux varies using a magnetization coil and permanent magnet hybrid structure



(a) Front and rear view from coil end

(b) Axial section along the line A-B

Fig.23. Configuration of a hybrid variable magnetic-force motor.

Analysis Results of Magnetization

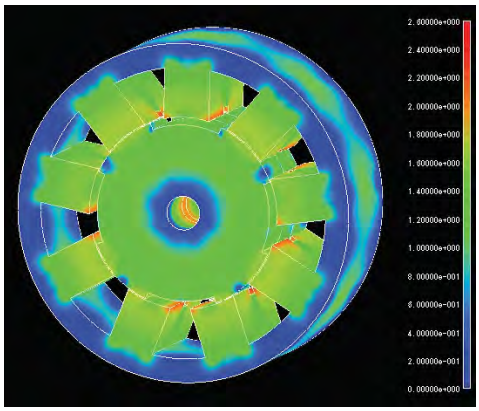


Fig. 8. Distribution of magnetic flux density at demagnetization.

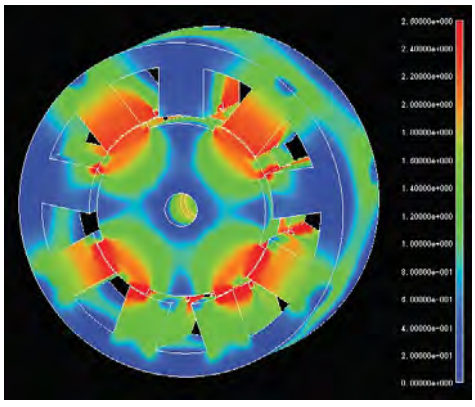


Fig. 9. Distribution of magnetic flux density at remagnetization.

Magnetic field analysis software: JMAG

Fig. 24. Distribution of magnetic flux density of a hybrid variable magnetic-force motor.

Change in inductive voltage during demagnetization

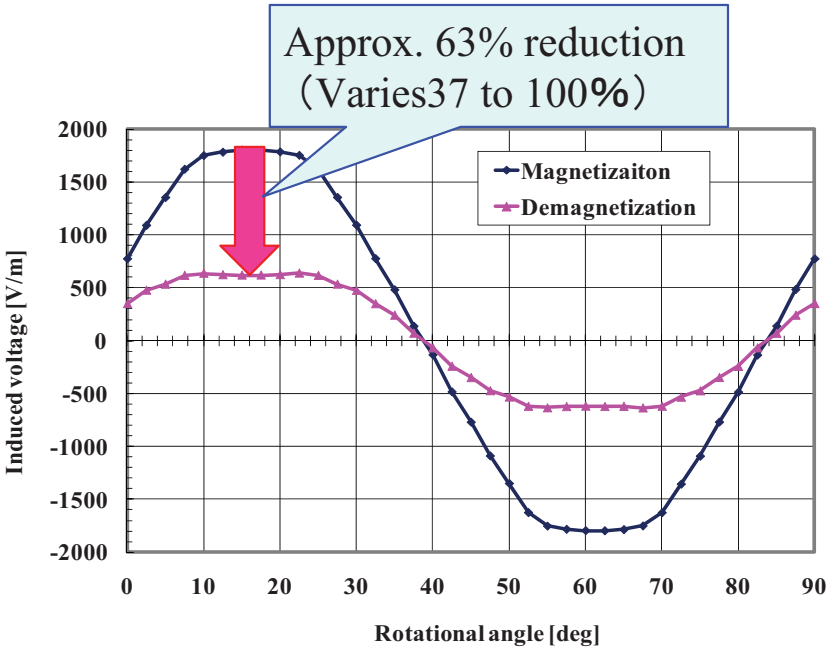


Fig. 25. Change of induced voltage due to variable flux.

6. China: Variable magnetic flux motor (testing level)

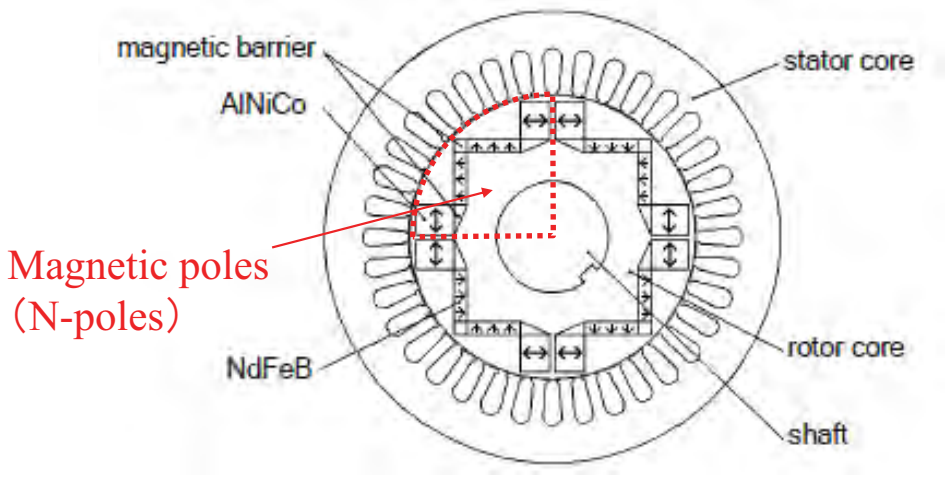
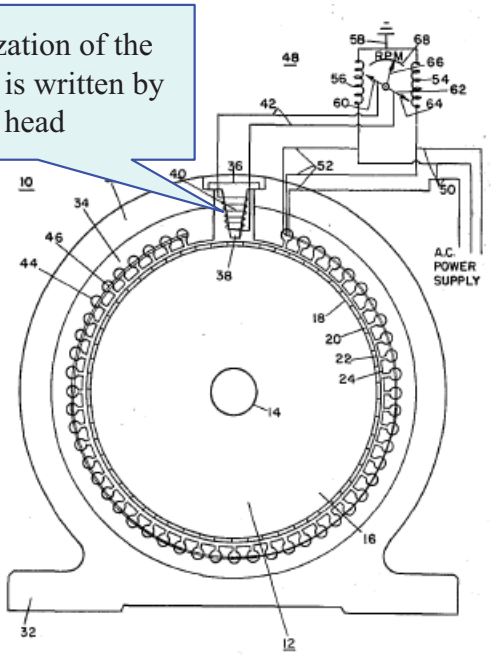


Fig. 26. Controllable-flux PMSM.

Reference [8]

7. America: Magnetization Type Motor/Generator

The magnetization of the rotor magnet is written by the magnetic head



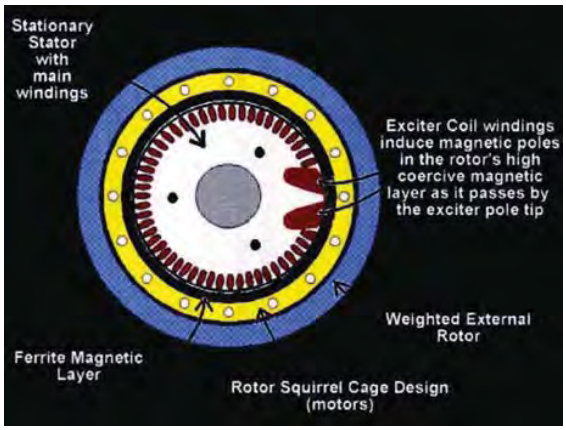


Fig. 27. Written-pole machine (Roesel Generator).

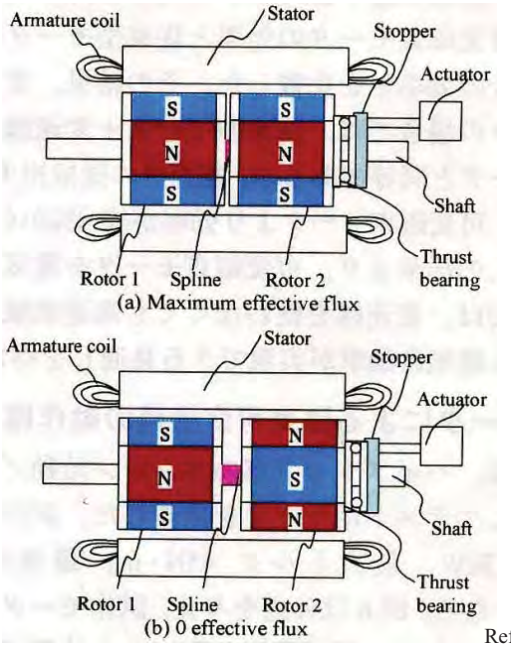
Reference [9]

8. Hitachi: Mechanical Type Variable Magnetic Flux Motor

Structure:
Rotor divided in half in the axial direction
＋actuator

Method to vary magnetic flux:
The phase is displaced circumferentially for the divided rotor.

Characteristics
Induced voltage varies 50 to 100%



Reference [10]

Fig. 28. Variable-magnetic-flux motor.

Many patents are in the works from Honda for mechanical offset in the cylindrical direction

9. In Closing

■Motor system for better energy conservation
Technology for realizing variable magnetic flux drives is obtained using better drive characteristics based on "face × time" rather than "point."

■ Variable magnetic flux motor
Electric formulas are starting to be used in a small capacity as electric formulas (variable magnetic flux) and mechanical formulas (magnetic offset) are researched and developed.

Variable magnetic flux motors should be effective in increasing the cruising time of electric vehicles and plug in HEV. A large step forward in energy conservation will be achieved by obtaining better variable magnetic flux motor drives.

Reference

[1] A. Weschta, "Schwachung des Erregerfelds bei einer dauermagneterregten Synchronmaschine" etz Archive Bd.7, pp.79-84 (1985)
[2] V. Ostovic, "Memory Motors" IEEE Industry Applications Magazine, Jan./Feb., pp.52-61 (2003)
[3] K.Sakai, K.Yuki, Y.Hashiba and N.Takahashi: "Principle and basic characteristics of the variable-magnetic-force memory motor" , Proc. of the 2009 JIAS Conf.,3-10 (2009) (in Japanese).
[4] K. Sakai, etc.: "Principle of the Variable-Magnetic-Force Memory Motor", Proc. of the 12th International Conference on Electrical Machines and Systems, LS6A-1 (2009)
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[9] United State Patent 4,227,136," Variable speed A.C.Motor" John F.Rosel,Jr. Oct.7,1980.
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