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Impact Torque Analysis of New Electromagnetic Impact Mechanism Employing 3-D Finite Element Method

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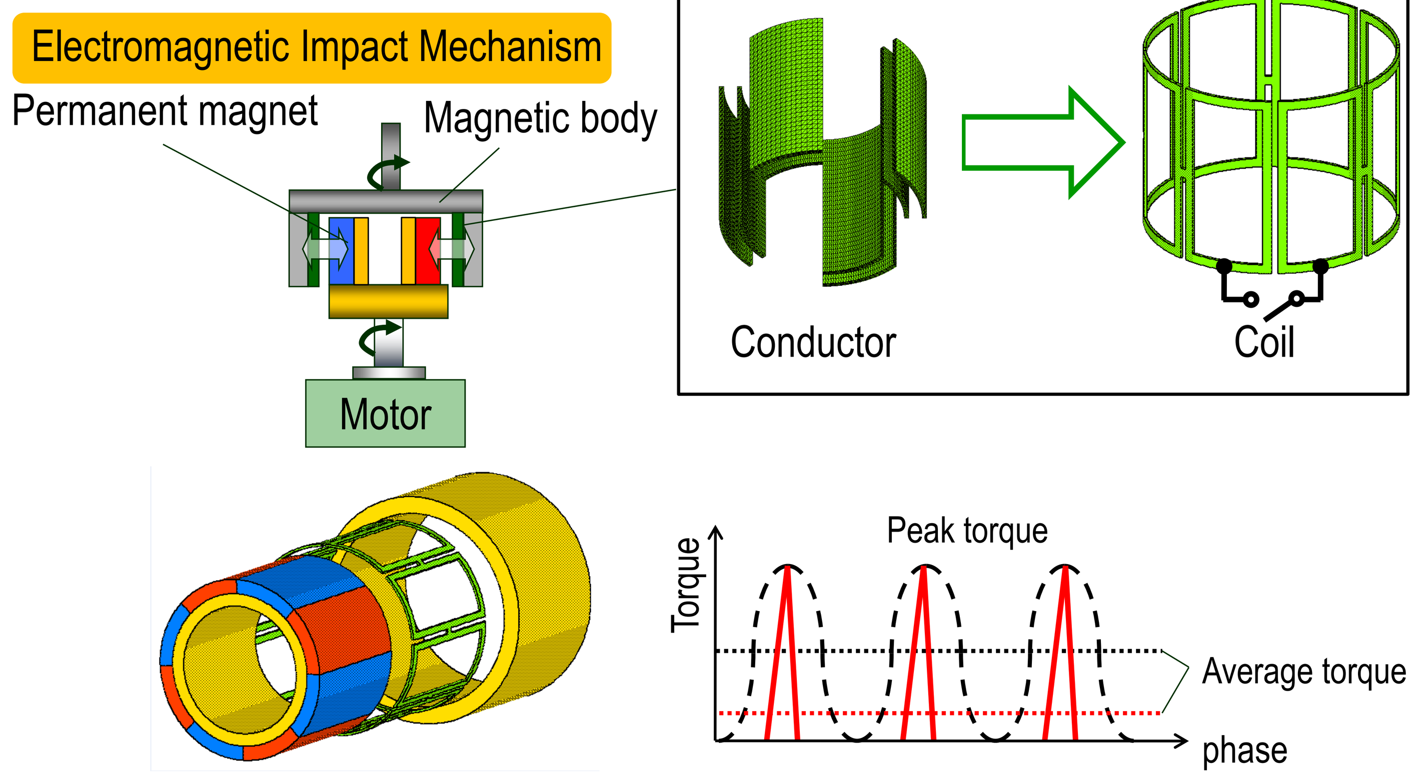
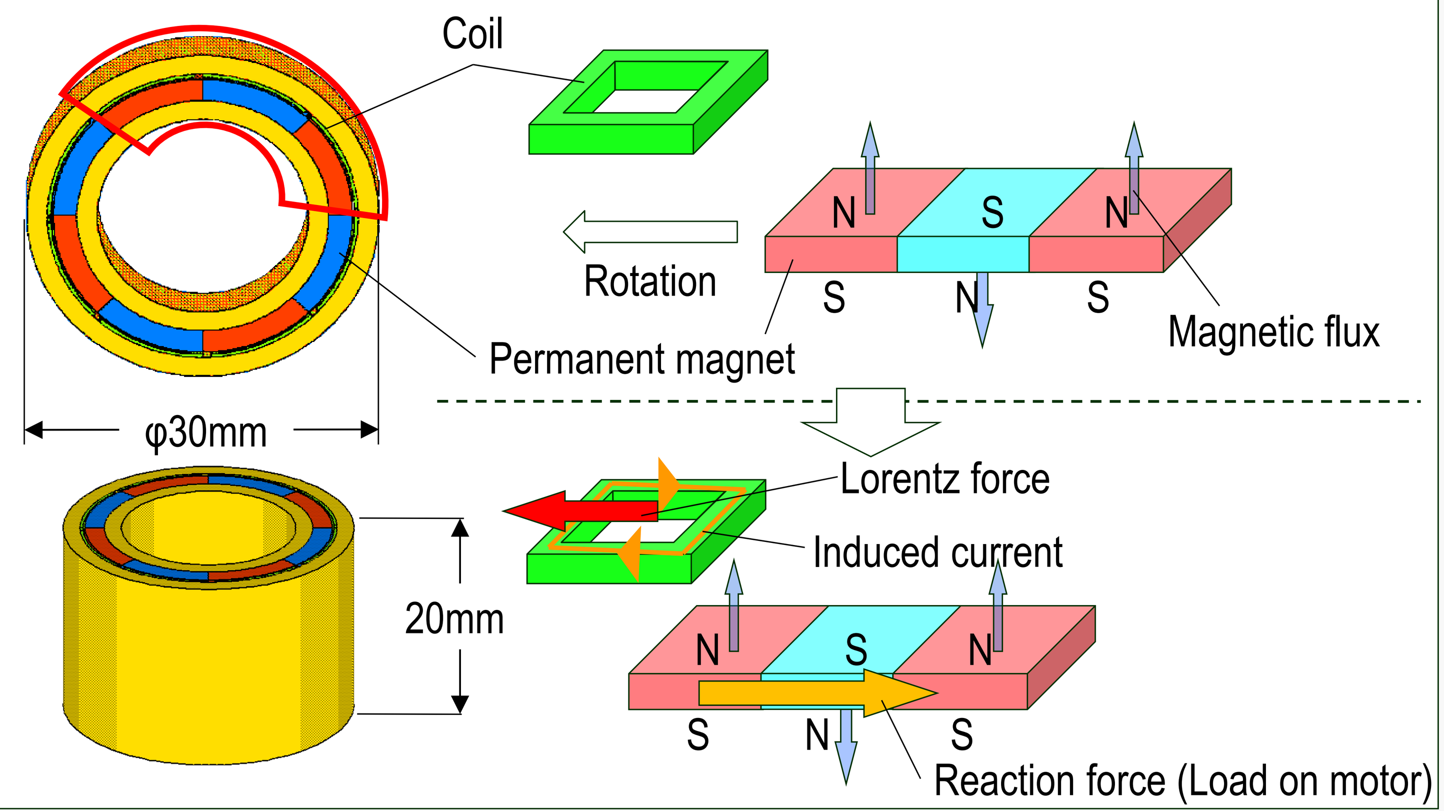
Introduction

- This paper describes impact torque characteristics of a new electromagnetic impact mechanism employing the 3-D FEM.
- In this mechanism, the induced current in a coil is controlled by switching current ON/OFF depending on the rotation angle of a rotor magnet in order to reduce average torque.
- The effectiveness of this mechanism is verified by carrying out the measurement on a prototype.



Operational Principle

- The multi-magnetized ring magnet is rotated in high speed using a motor.
- The induced current flows in coils caused by the time variation of interlinkage magnetic flux of coils.
- The Lorentz force is generated from the induced current and the magnetic flux of the ring magnet.
- The reaction force acts on the rotor as a brake, which is also the load on the motor.



Analysis Method and Conditions

Magnetic field and electric circuit analysis

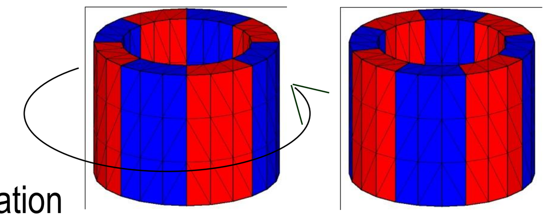
$$\mathrm{rot}(\nu\,\mathrm{rot}\,\boldsymbol{A}) = \boldsymbol{J}_e + \nu_0\,\mathrm{rot}\,\boldsymbol{M} \qquad \boldsymbol{J}_e = -\sigma\left(\frac{\partial \boldsymbol{A}}{\partial t} + \mathrm{grad}\,\phi\right)$$

$$\mathrm{div}\,\boldsymbol{J}_e = 0 \qquad E = -RI_0 - \frac{d\Psi}{dt} = 0$$

where $\boldsymbol{A}$ is the magnetic vector potential, ν is the reluctivity of magnetic material, $\boldsymbol{J}_e$ is the eddy current density, ν_0 is the reluctivity of vacuum, $\boldsymbol{M}$ is the magnetization, σ is the conductivity, I_0 is the current, and Ψ is the interlinkage flux of induction coils. R is assumed 1MΩ when coils are open, and 1.4Ω when coils are closed..

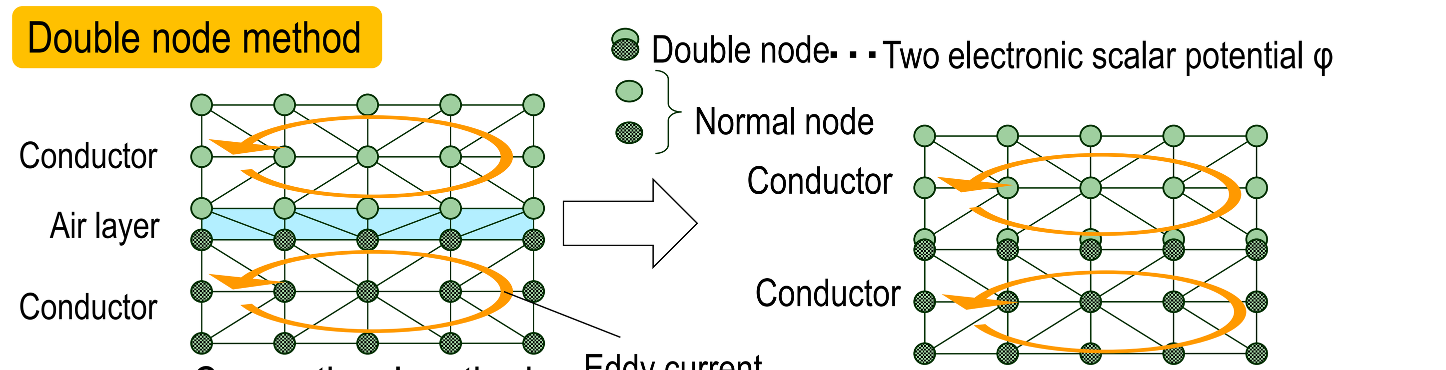
Rotation motion analysis

(1) The rotation magnet region is equally divided according to rotation speed and time interval.
(2) The material data and magnetization directions of the rotation magnet are changed in every step for the rotation motion analysis. The rotation speed of magnet is constant.



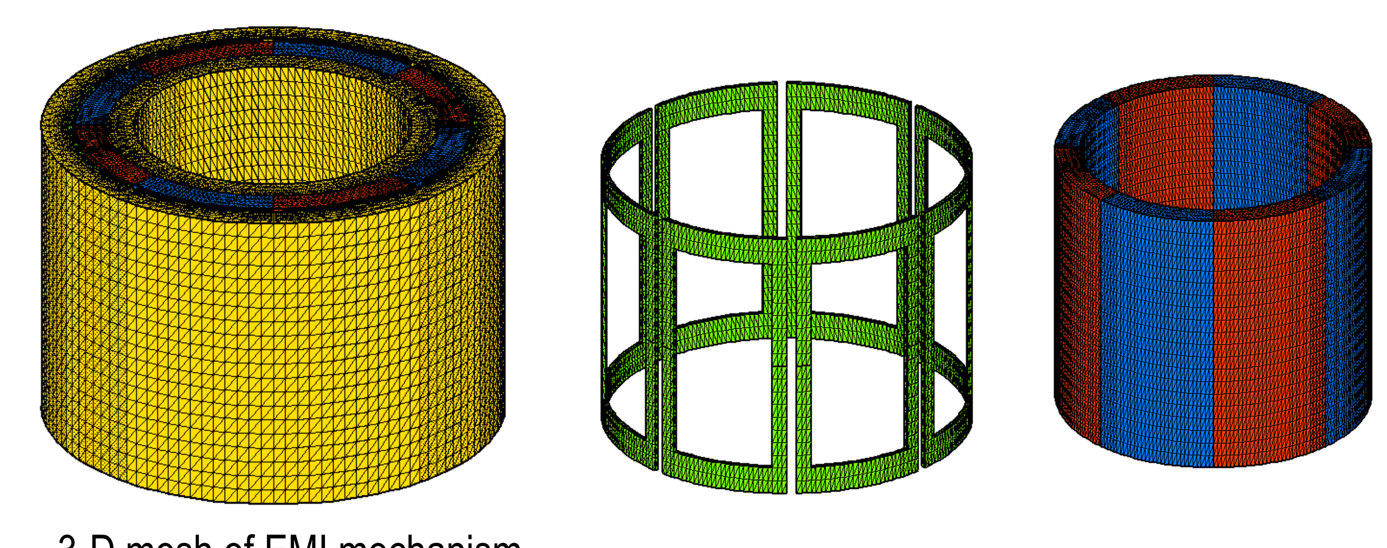
(a) Initial position (b) 1st step

Double node method



Conventional method Double node method

Analyzed Model



3-D mesh of EMI mechanism except air | Coil | Permanent magnet

Discretization Data and CPU Time

Number of elements	898,740
Number of edges	1,064,449
Number of unknown variables	1,032,691
Number of time steps	31
CPU time (hour)	17

Specification of Coil

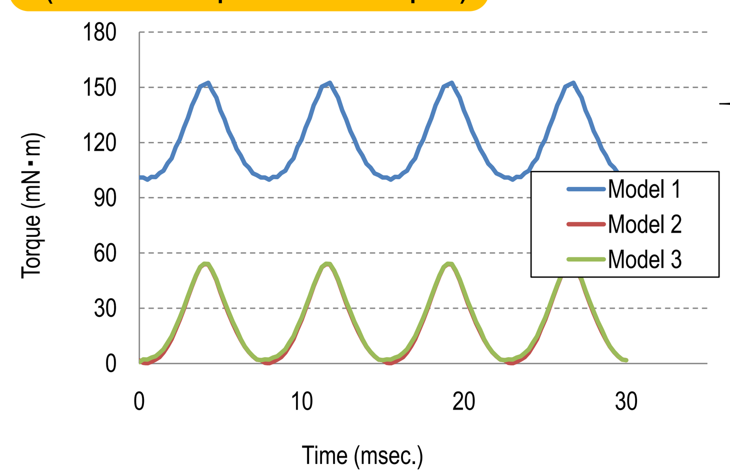
Turns	12×8
Resistance(Ω)	1.4
Diameter of wire(mm)	0.6

Specification of Permanent magnet

Magnetization of magnet(T)	1.4
Pole number	8

Influence of Eddy Current

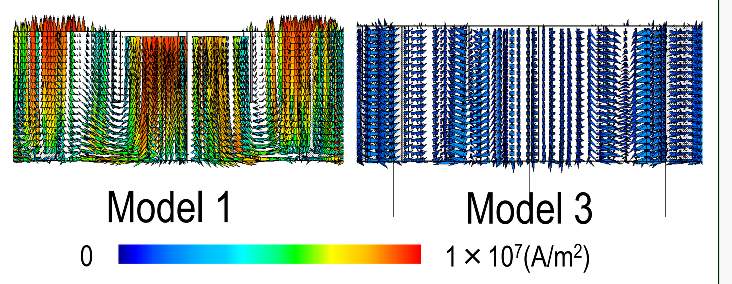
Dynamic Characteristics (Rotation speed :1000rpm)

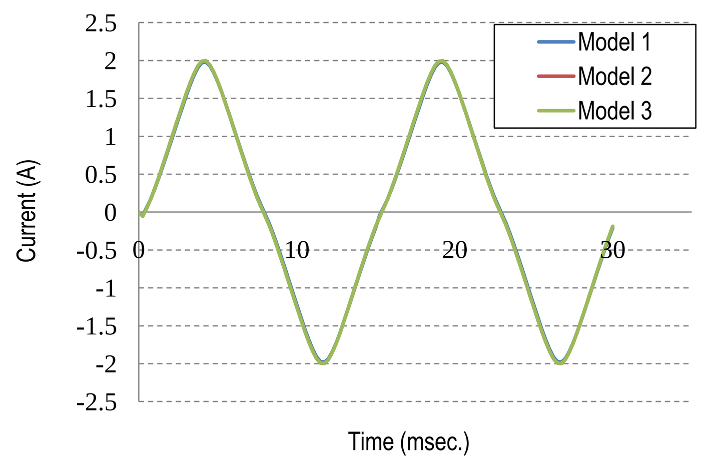


Torque characteristic

The Condition of Model

Model 1 : Eddy current is considered
Model 2 : Eddy current is not considered
Model 3 : The outer core is composed of silicon steel lamination





Current characteristic

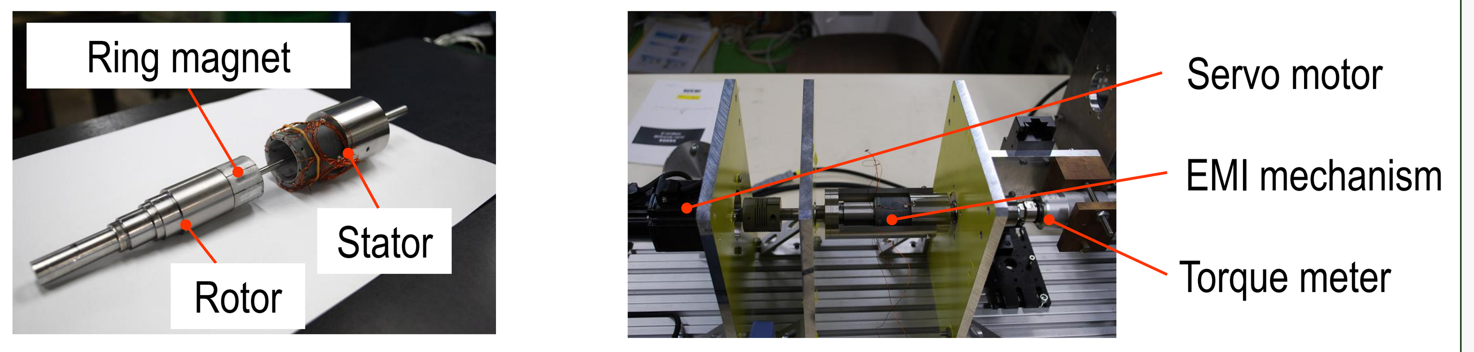
Maximum Torque (Average Torque)

Model 1 : 152mN・m(125mN・m)
Model 2 : 54mN・m(22mN・m)
Model 3 : 54.2mN・m(22mN・m)

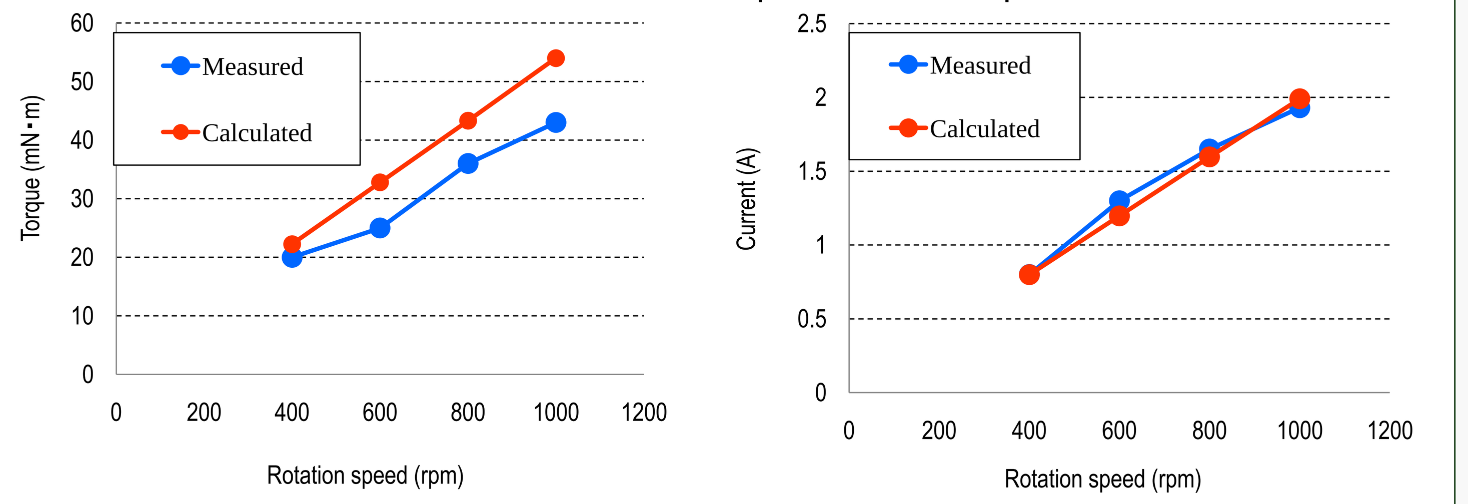
Maximum Current

Model 1, Model 2, Model 3 : ±2A

Verification by Experiment



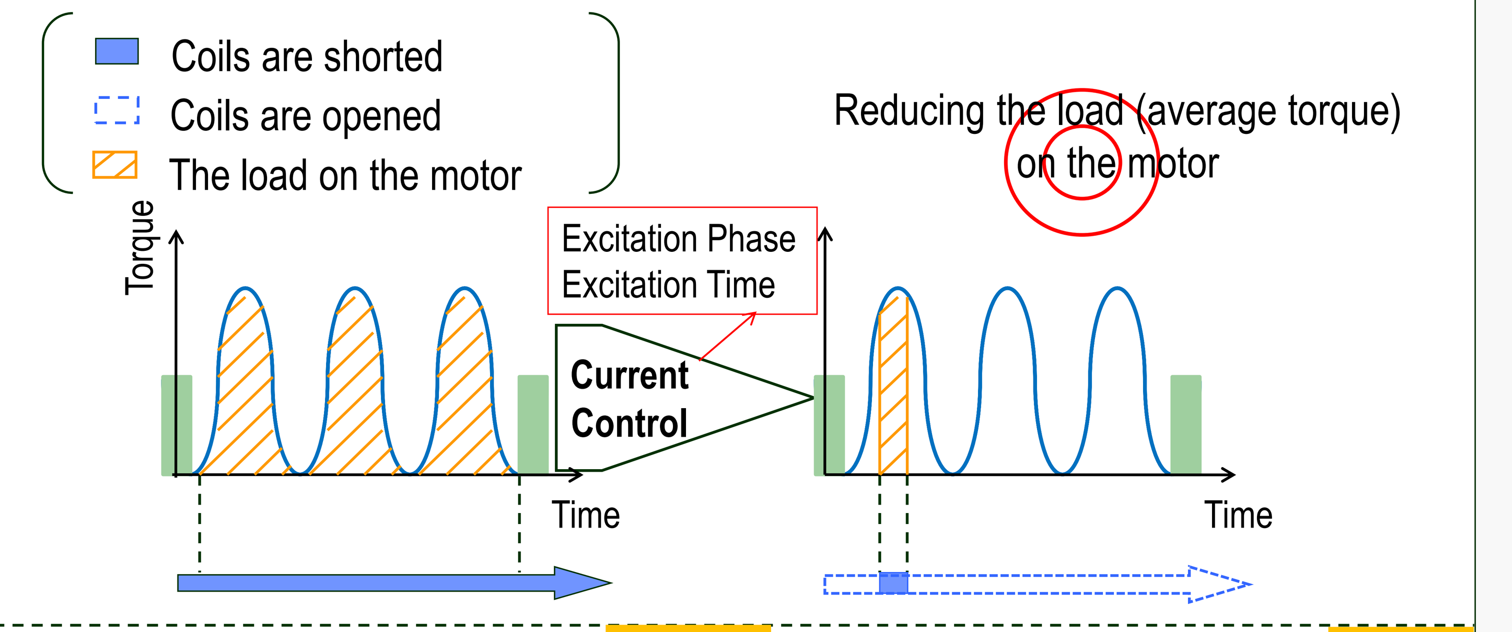
Prototype Experimental setup

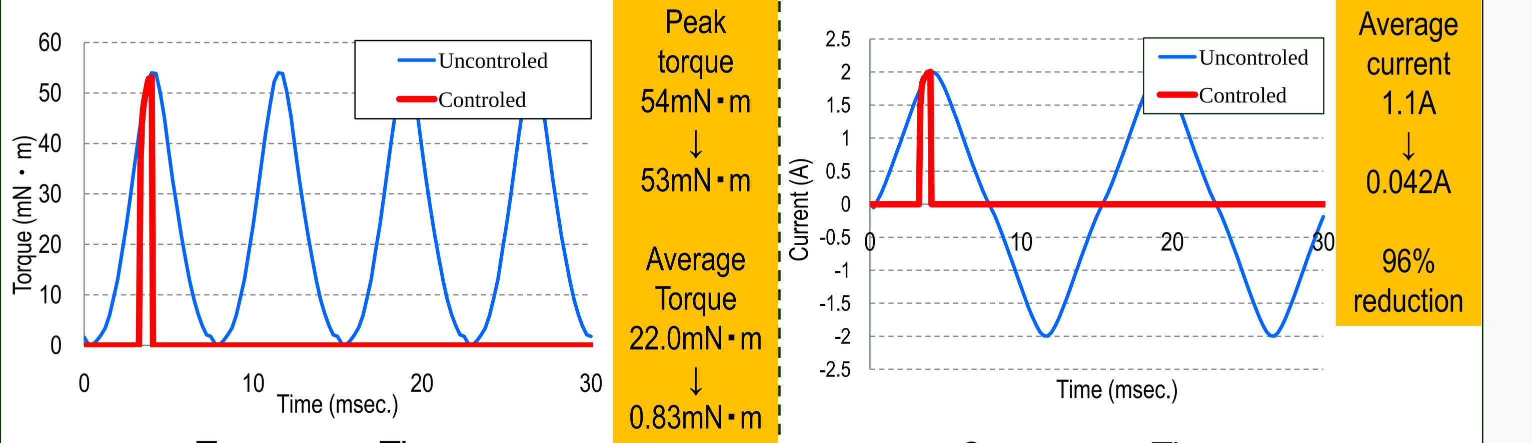


Peak Torque v.s. Rotation speed Peak Current v.s. Rotation speed

1. Analyzed peak current agree well with the experimental results.
2. Analyzed peak torque is a little higher than the experimental results at each rotation speed. This difference is thought to the measurement error.

Current Control Method





Torque v.s. Time (at 1000rpm) | Current v.s. Time (at 1000rpm)

Conclusion

- This paper proposed a new electromagnetic impact mechanism by switching current ON/OFF depending on the rotation angle of a rotor magnet in order to reduce average torque.
- The usefulness of this mechanism was shown by the computed results by the 3-D FEM.
  - *Peak torque almost keeps the same value (54⇒53mN・m)
  - *Average torque decreases about 96% (22.0 ⇒ 0.83mN・m)
  - *Average current decreases about 96% (1.1 ⇒ 0.042A)
- The validity of the analysis was confirmed by carrying out the measurement on a prototype under no current control.