Basic Investigation on Magnetic Pole Changing Type Linear Stepping Actuator using Inverse Magnetostrictive Effect. (With JMAG Simulation)

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Abstract :
This motor consists of a permanent magnet, iron yoke and four GMM rods, which the magnetostriction controlled by PZT changes the flux distribution on four magnetic poles. This motor has advantages of low power consumption and low heat generation compared with a conventional system with electromagnetic actuators.

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Structuring Magnetic Circuits using the Inverse Magnetostrictive Effect of Magnetostrictive Elements

1. Converting Energy
2. Obtaining New Principles
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Example) Camera Module

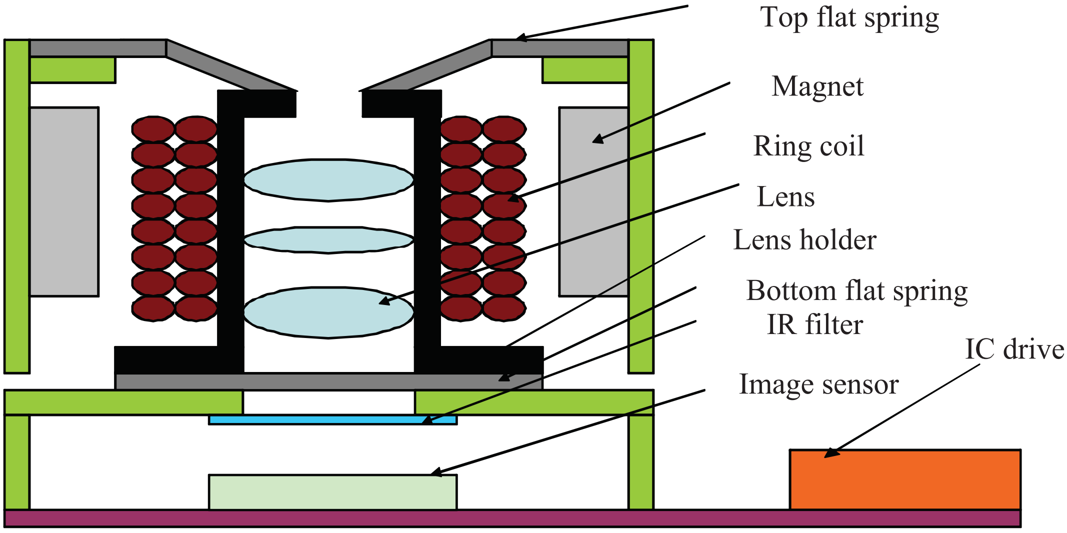

Figure of the primary example for current VCM (Voice Coil Motor) AF (Auto Focus) type camera modules

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Future Types of Drives

- Camera modules that support video will become necessary for cellular phones.
- A few seconds of excitation is only required for still photography using Voice Coil Motor type auto focus drives, but, in video, current has to continually flow in the coil for the lenses to keep up with the moving image causing heat produced by Joule losses. This is one of the challenges we will see in the future.

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Mobile Devices

- Lower power consumption is desired for the battery drive in mobile devices.
- No current and zero power consumption is especially desirable once the position is fixed.
- Countermeasures to heat are necessary because just like a coil, the loss changes to heat which can effect the control system, position sensor, and body worsening the accuracy of the positioning device (no area to dissipate heat).

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New Types of Actuators

- **Shape memory alloy** : Geometry varies by heat --> Response slows
- **Piezoelectric material** : Geometry varies by voltage (Inverse piezoelectric effect)
  : Voltage is produced by the changes geometry (piezoelectric effect) --> The short stroke is a drawback
- **Magnetostrictive materials** : Geometry varies by the magnetic field (magnetostrictive effect)
  : Magnetization varies by changes in geometry (inverse magnetostrictive effect)
- **Magnetostriction** -- Geometry variations caused by magnetic fields

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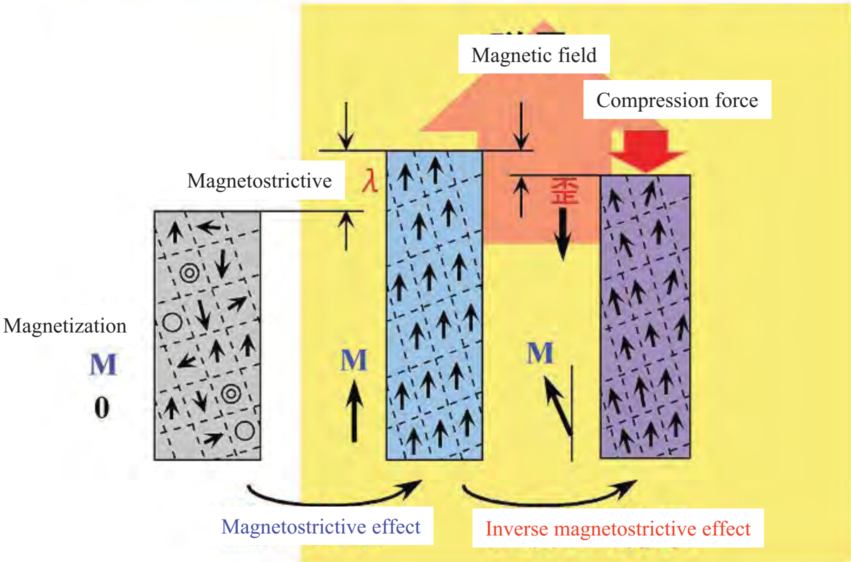
Magnetostrictive Effect and Inverse Magnetostrictive Effect

The geometry of magnetic materials vary with the magnetization (magnetostrictive effect).
The magnetization varies with the variations in geometry (inverse magnetostrictive effect).



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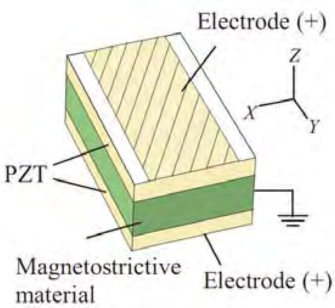
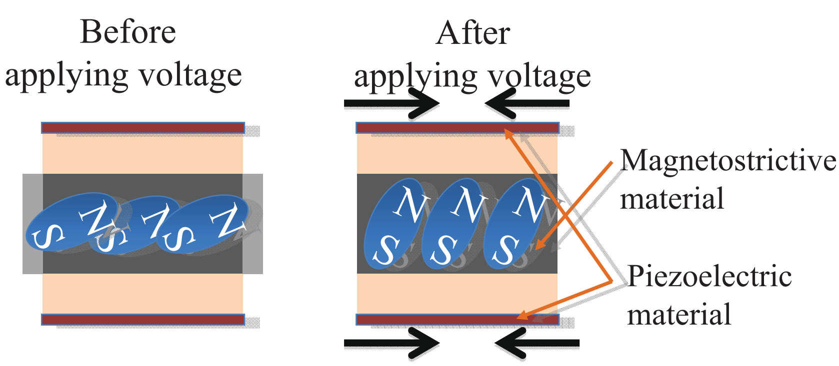
Proposed by Mr. Ueno and staff
(Kanazawa University)

Magnetic force control devices constructed by layering magnetostrictive and piezoelectric material are being proposed.





Variations in magnetic resistance

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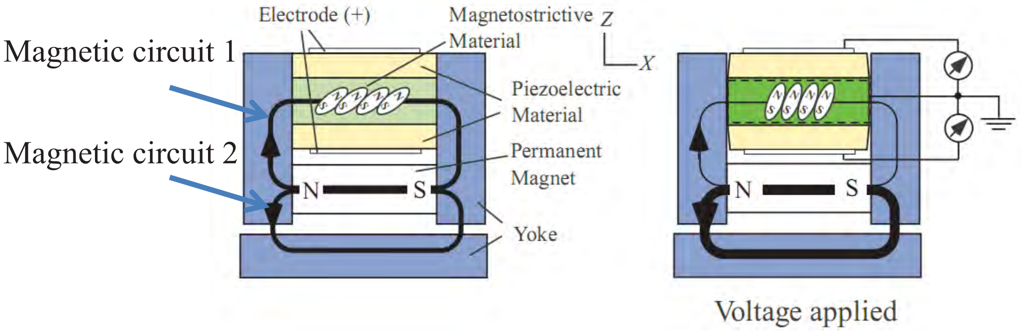
Magnetic Attractive Force Model

(Mr. Ueno and staff, Kanezawa University)



The component is composed of a layered body of magnetostricitve material sandwiched between piezoelectric material as well as permanent magnets and a magnetic yoke for the magnetic field.
The piezoelectric material is polarized in the height direction (Z direction). The face contacting the magnetostrictive material is the ground and the opposite face is the + pole.
The piezoelectric layers shrink in the X-direction because of the piezoelectric effect when voltage is applied to both layers and the compression force loads the magnetostrictive material. In other words, the magnetization in the X-direction is controlled by the applied voltage.
The component composed of the layered body, permanent magnets (magnetization in the X-direction), and yoke utilizes the magnetic force acting through the gap on the external yoke.
The electromagnetic force of the yoke can be controlled by the compression force of the piezoelectric element that has the parallel magnetic pathways of Magnetic Circuit 1 and Magnetic Circuit 2.

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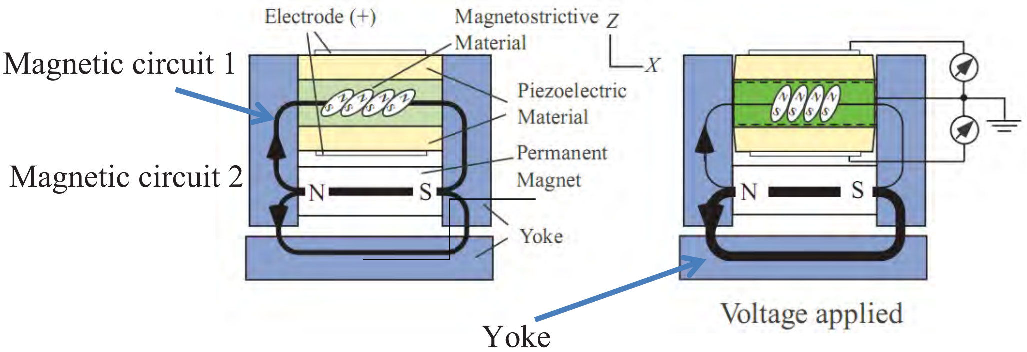
Sensing



The magnetic flux flowing in the magnetostrictive element can be also be varied by changing the distance of the yoke.
This is magnetostrictive and deforming the piezoelectric element making sensing possible.
A sensor that doesn't require power, such as the Hall effect sensor, can be used.

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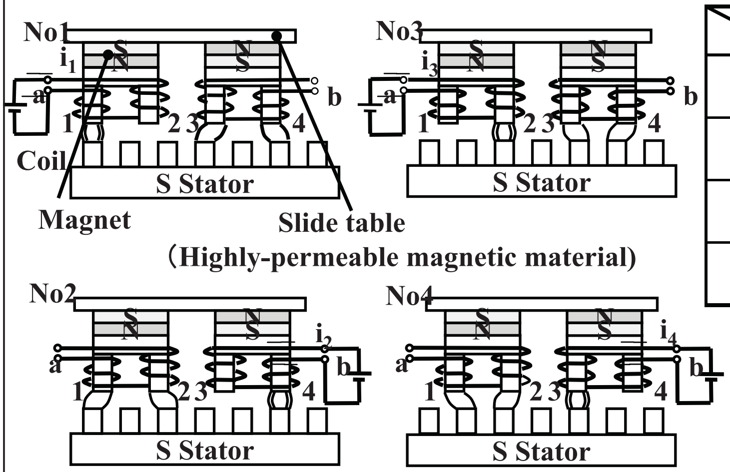
Sawyer principle (coil type excitation)



	Excitation coil/ current direction	Ratio of magnetic force				Steady pole	Displacement
		1-pole	2-pole	3-pole	4-pole		
No1	a						
	i_1	2	0	1	1	1	0 (start)
No2	b						
	i_2	1	1	0	2	4	½ pitch
No3	a						
	i_3	0	2	1	1	2	1 pitch
No4	b						
	i_4	1	1	2	0	3	1 ½ pitch

Operating principles of a hybrid linear stepping motor

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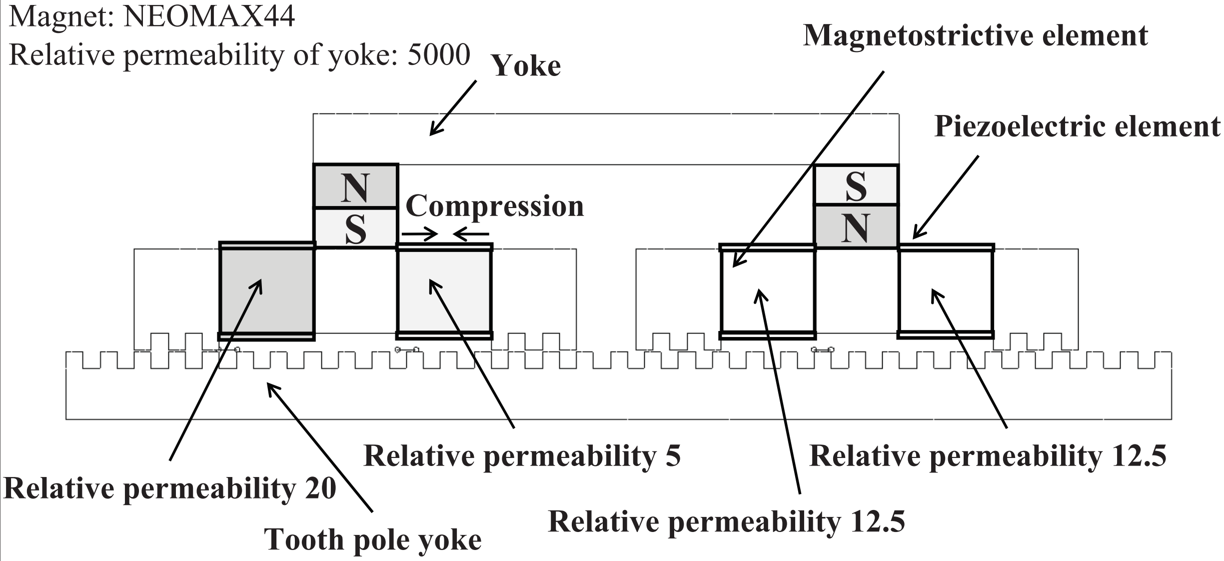
Sawyer principle (relative permeability type variations)

Magnet: NEOMAX44
Relative permeability of yoke: 5000



The relative permeability of the magnetostrictive element is 5 when compressed to maximum.
The relative permeability is 20 when stretched to maximum.

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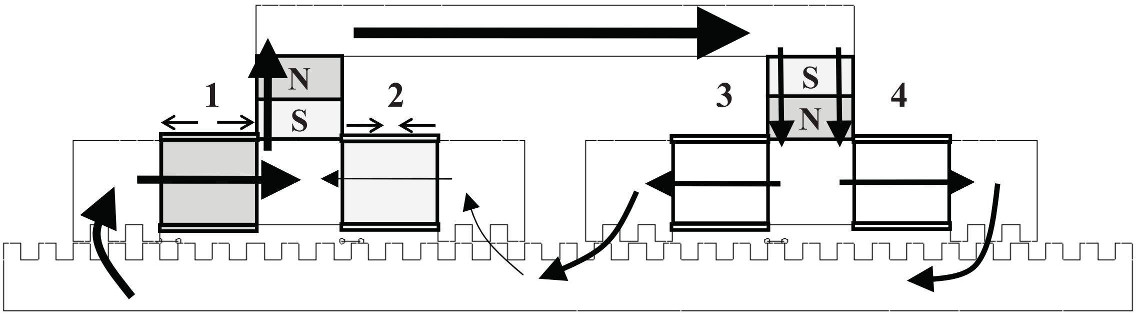
Sawyer principle (relative permeability type variations)

Arrows: Flow of magnetic flux



The thickness of the arrows indicates the magnetic flux density for the relative permeability of the 4 magnetostrictive elements which varies by compressing the piezoelectric elements. Therefore, for this linear stepping drive, the relative permeability of No.3 is 20, No.4 is 5, No1 and 2 are 12.5, and drives a half step per magnetic pole tooth.

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Premise for Simulations

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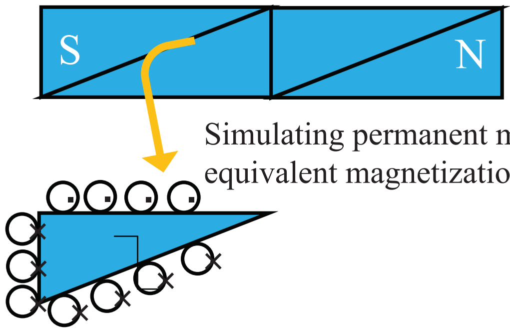
Electromagnet Design Including Permanent Magnets

Permanent magnets



Simulating permanent magnets by equivalent magnetization current

Simulating permanent magnets

Equivalent magnetization current

Basic equation for permanent magnets

The magnetic characteristics of permanent magnets is simulated using magnetization, ***M***, to analyze regions including permanent magnets. If the magnetic properties of the permanent magnets are the magnetic flux density, ***B***, field intensity, ***H***, permeability of air, μ_0, then:

$$\boldsymbol{B} = \mu_0 \boldsymbol{H} + \boldsymbol{M}$$

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Ampere's circuital integral law is applied to the previous equation:

$$rot \frac{1}{\mu_0}(\boldsymbol{B} - \boldsymbol{M}) = \boldsymbol{J_0}$$

$\boldsymbol{J_0}$ indicates the current density and ***B*** expresses the vector potential ***A***.

$$rot\, \nu_0 (rot\boldsymbol{A} - \boldsymbol{M}) - \boldsymbol{J_0} = 0$$

ν_0 expresses the magnetic resistivity of air ($=1/\mu_0$). The above equation is transformed to:

$$\nu_0 rotrot\boldsymbol{A} = \boldsymbol{J_0} + \nu_0 rot\boldsymbol{M}$$

The 2 component on the right side of the above equation is produced by the magnetization. The current has the same movement. This expressed as the equivalent magnetization current $\boldsymbol{J_m}$ is:

$$\boldsymbol{J_m} = \nu_0 rot\boldsymbol{M}$$

The magnetic field in the permanent magnets is expressed by adding the equivalent magnetization current $\boldsymbol{J_m}$ using the conventional Poisson equation.

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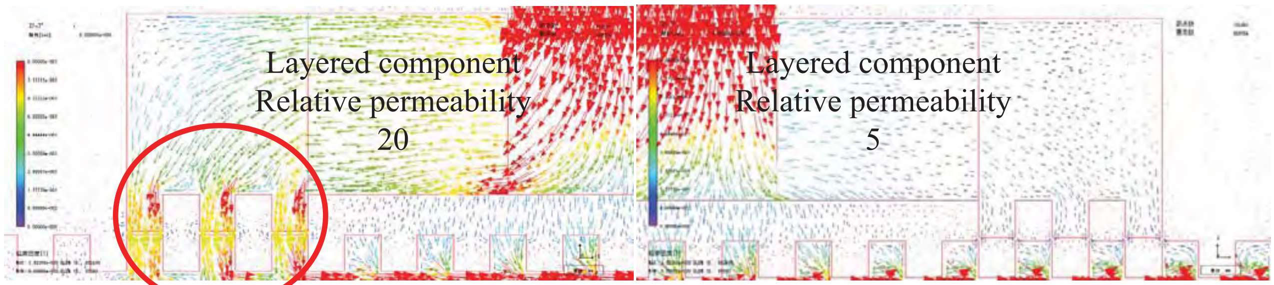
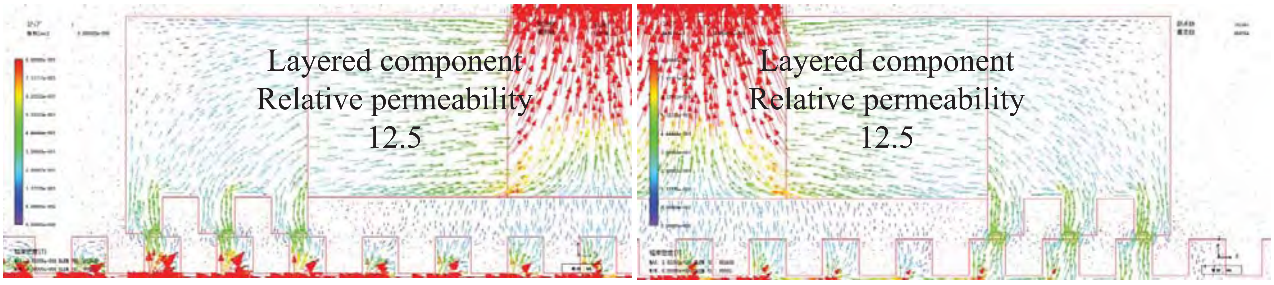
1^{st} step



Magnetic flux density RED:MAX0.8T



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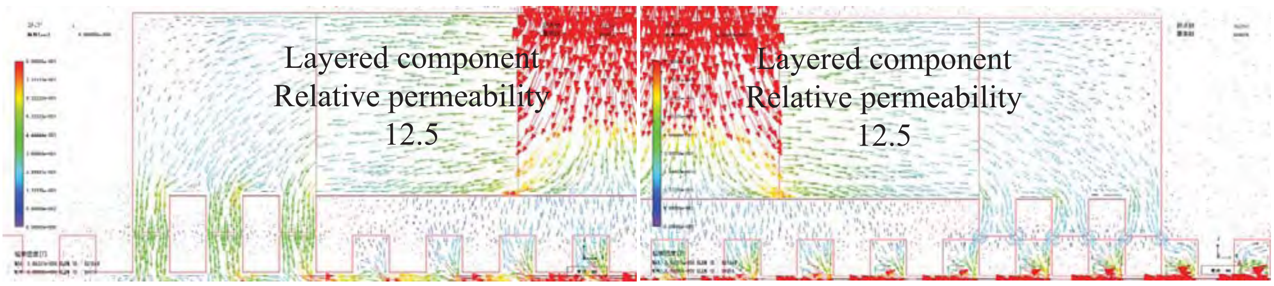
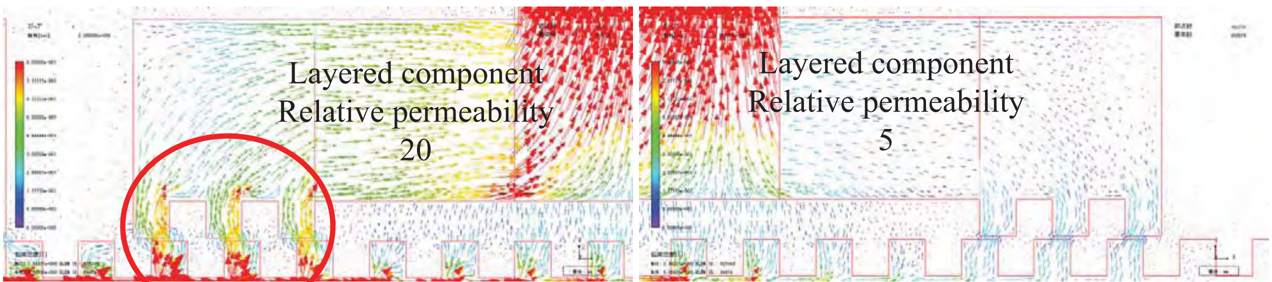
2^{nd} Step



Magnetic flux density RED:MAX0.8T



→ 38g

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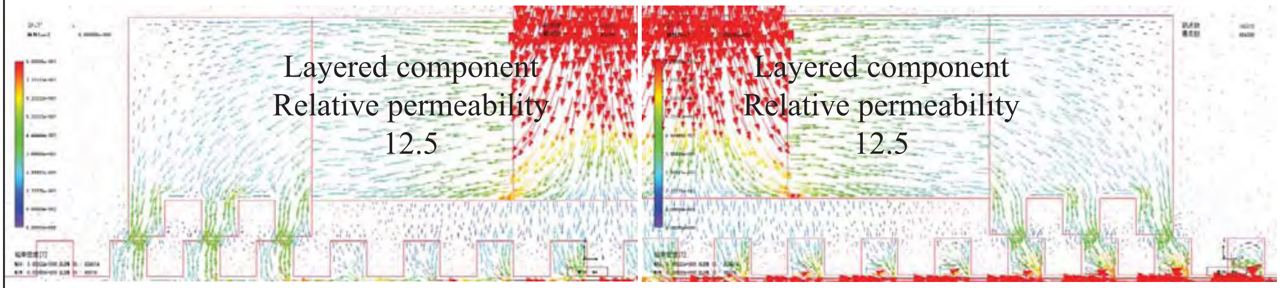
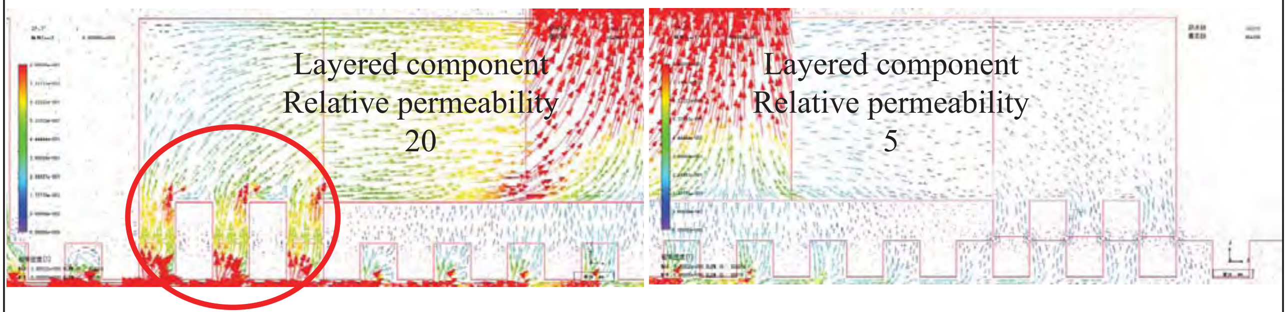
3rd Step



Magnetic flux density RED:MAX0.8T



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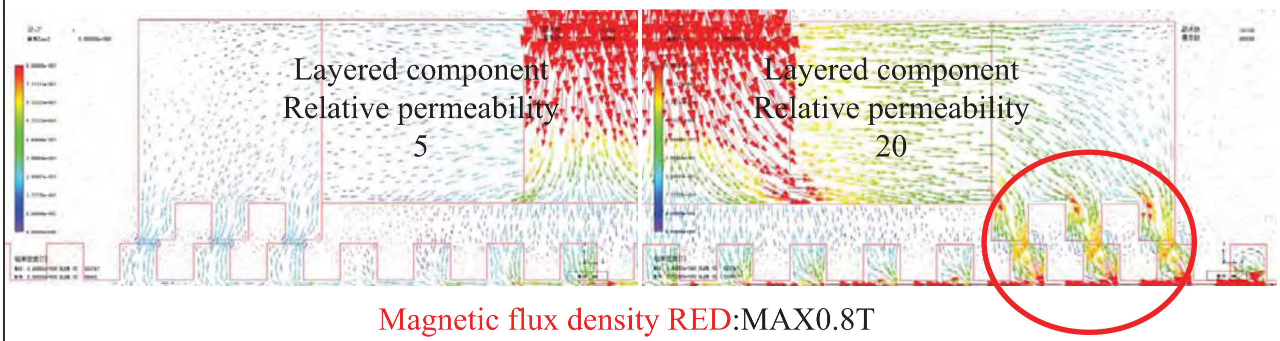
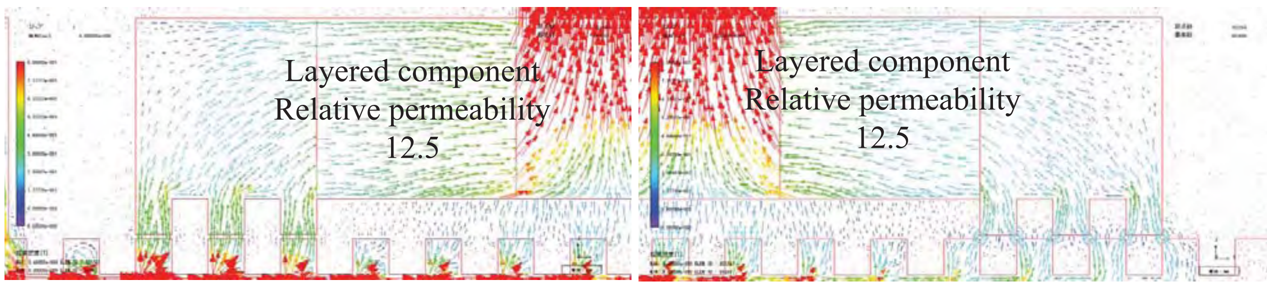
4th Step



Magnetic flux density RED:MAX0.8T



→ 39.7g

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Conclusion

- The magnetic flux pathways for the magnetic flux density of permanent magnets can be controlled by controlling the magnetic resistivity variations in the piezoelectric element by deforming the magnetostrictive element without using a coil, which theoretically confirms a stepping drive based on the Sawyer principles is possible.
- Development will continue toward further miniaturizing the magnetic force control component using magnetostrictive materials for applications in mobile devices.

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Variations in Relative Permeability

Components that were once not considered as variables will be examined as variables.

→ However, new developments in materials is vital...

Variations in Magnetic Flux Density

→ How do we distribute and vary these magnetic fields?

Energy conservation should also be considered.

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