Analysis of Core Materials Characteristics of Non-Contact Linear Position Sensor on Impedance Characteristics

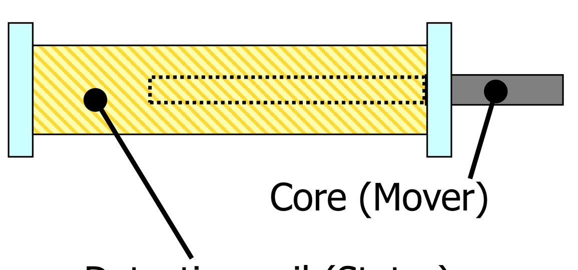
Intelligent Actuators and Sensors Laboratory
Department of Adaptive Machine Systems, Osaka University, Osaka, 565-0871, Japan
Tel : +81-6-6879-7553, Fax : +81-6-6879-7553

INTRODUCTION

● The mechanical contact type potentiometer that has been conventionally used as a position sensor is pointed out the problems of contact reliability, life time, and so on.
● We are developing the non-contact magnetic position sensor using impedance change according to the displacement.
● The magnetization characteristics of a core material greatly influence the impedance of coil, especially in high frequency. Therefore, it is effective to clarify the impedance characteristics by the 3-D finite element analysis.

We analyze the AC magnetization characteristics of various core materials used for a position sensor using 3-D FEM which taken into account the complex permeability. Moreover, the influence of the permeability and the electric conductivity of various kinds of core materials on the impedance characteristics of a linear position sensor are clarified, and the suitable core material for this sensor is discussed. The validity of the method is clarified through the comparison with the measurement.

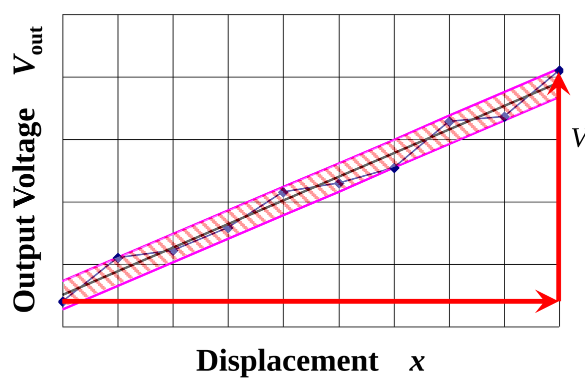
BACKGROUND

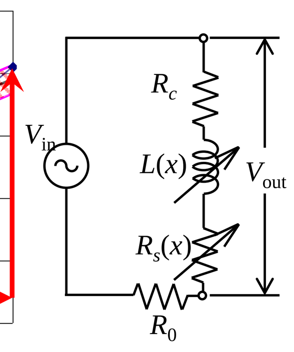


Magnetic structure
using impedance change against displacement

Merits

- Large stroke
- Stroke direct detecting is possible
- Simple structure and low cost etc.





$Z(x)=\sqrt{(R_c+R_s(x)+R_0)^2+(2\pi f L(x))^2}$

$V_{out}=V_{in}\left(1-\frac{R_0}{Z(x)}\right)$

Linearity
Sensitivity
vs.
Displacement

These are greatly influenced in high frequency. Therefore, for calculating correctly, it is important the considering of magnetization characteristics of a core material.

ANALYSIS METHOD

A. Magnetic Filed Analysis by FEM

The fundamental equation of the magnetic field can be indicated in frequency domain as follows.

$$\begin{cases} \mathrm{rot}(\dot{\nu}\,\mathrm{rot}\,\dot{\boldsymbol{A}}) = \dot{\boldsymbol{J}}_0 + \dot{\boldsymbol{J}}_e = \dot{\boldsymbol{J}}_0 - \sigma(j\omega\dot{\boldsymbol{A}} + \mathrm{grad}\dot{\phi}) \\ \mathrm{div}\dot{\boldsymbol{J}}_e = 0 \end{cases}$$

B. Coupled Analysis with Electric Circuit

The electric circuit equation is coupled with the magnetic field equation.

$$\dot{V}_0 = R\dot{I}_0 + j\omega\dot{\psi}$$

$\dot{\nu}$: the magnetic reluctivity
$\dot{\boldsymbol{J}}_0$: the exciting current density
$\dot{\boldsymbol{J}}_e$: the eddy current density
σ : the electric conductivity
ω : the angular frequency
$\dot{\boldsymbol{A}}$: the magnetic vector potential
$\dot{\phi}$: the electric scalar potential
$\dot{V}_0$: the applied voltage
R : the resistance
$\dot{I}_0$: the exciting current
$\dot{\psi}$: the interlinkage flux of exciting coil
Dot (•) means complex number.

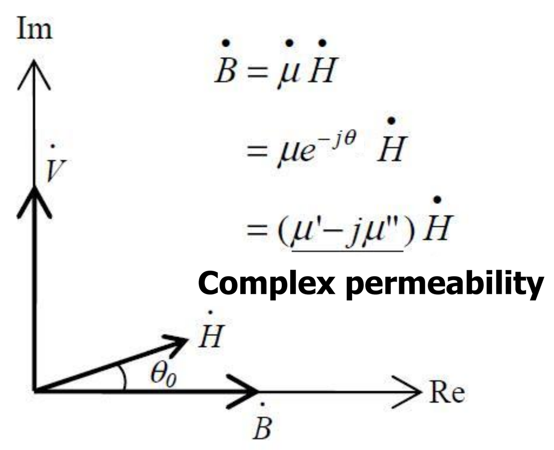
COMPLEX MAGNETIC PERMEABILITY

BASIC THEORY

$\dot{\mu} = \mu' - j\mu''$

Magnetic field strength is shown in complex number as $H=H_0\cos\omega t$, then magnetic flux density is shown as $B=B_0\cos(\omega t-\theta)$. Here, θ is phase angle. They are expressed as (1) using an exponential function.

Magnetic permeability $\dot{\mu}$ is determined as (2) from above H, B.



$$(1)\quad \begin{cases} \dot{H} = H_0 e^{j\omega t} \\ \dot{B} = B_0 e^{j(\omega t-\theta)} \end{cases}$$

$$(2)\quad \dot{\mu} = \frac{\dot{B}}{\dot{H}} = \frac{B_0 e^{j(\omega t-\theta)}}{H_0 e^{j\omega t}} = \frac{B_0}{H_0}e^{-j\theta} = \frac{B_0}{H_0}\cos\theta - j\frac{B_0}{H_0}\sin\theta$$

$$(3)\quad \boxed{\mu' = \frac{B_0}{H_0}\cos\theta,\quad \mu'' = \frac{B_0}{H_0}\sin\theta}$$

HOW TO USE of COMPLEX PERMEABILITY in FEM

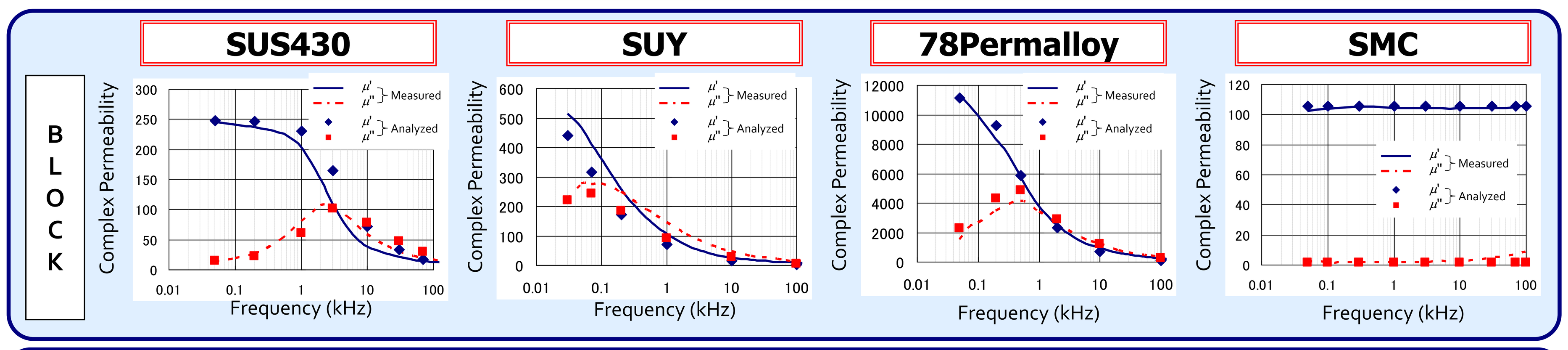
The measured real and imaginary part of complex magnetic permeability includes iron loss (eddy current loss and hysteresis loss), especially at high frequency, the influence of the eddy current is large.
Therefore, **the complex magnetic permeability measured at low frequency** has to be used in the analysis because the eddy current is considered in our FEM code.

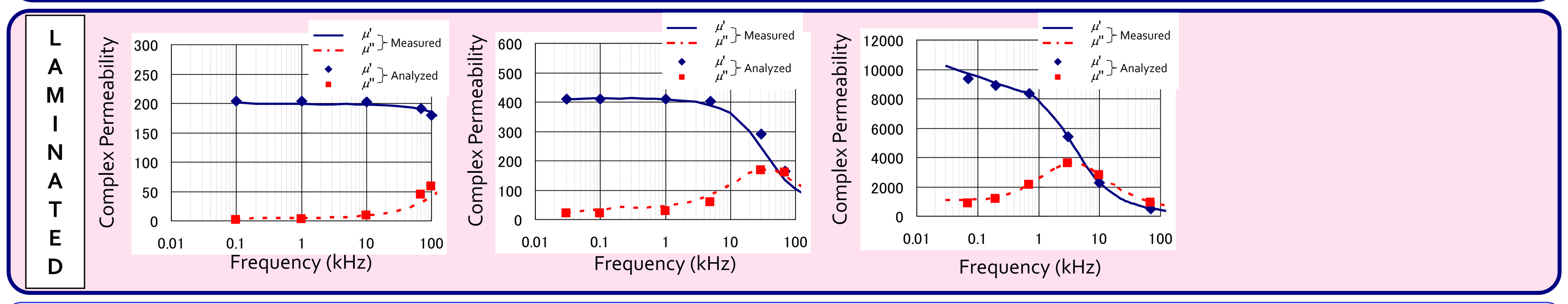
VERIFICATION of CORE MATERIAL CHARACTERISTICS

SPECIFICATIONS of CORE MATERIALS

Material	SUS430		SUY	
	Block	Lamination	Block	Lamination
Complex Permeability $\dot{\mu}$	$246-j12$	$201-j1.58$	$531-j119$	$406-j19$
Conductivity σ (S/m)	1.40 x 10^6		9.00 x 10^6	

Material	78Permalloy		SMC	
	Block	Lamination	Block	Lamination
Complex Permeability $\dot{\mu}$	$11482-j1248$	$9346-j879$	$104-j1.7$	—
Conductivity σ (S/m)	1.82 x 10^6		0.5	

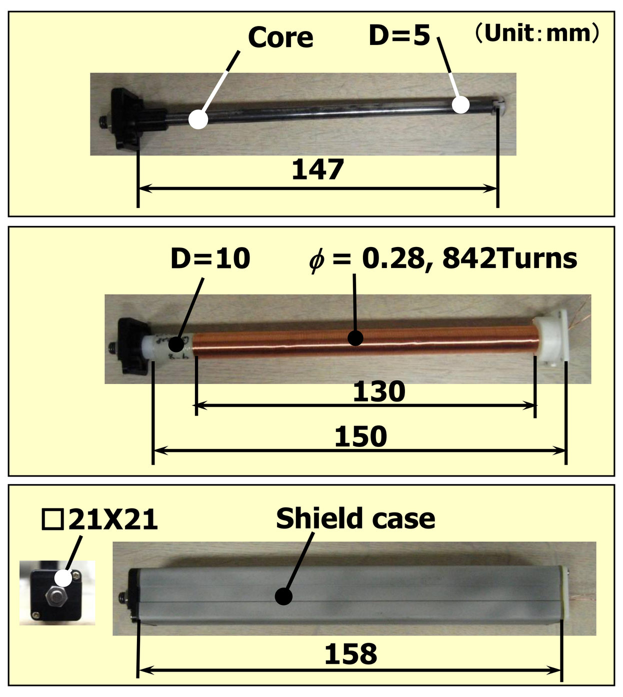




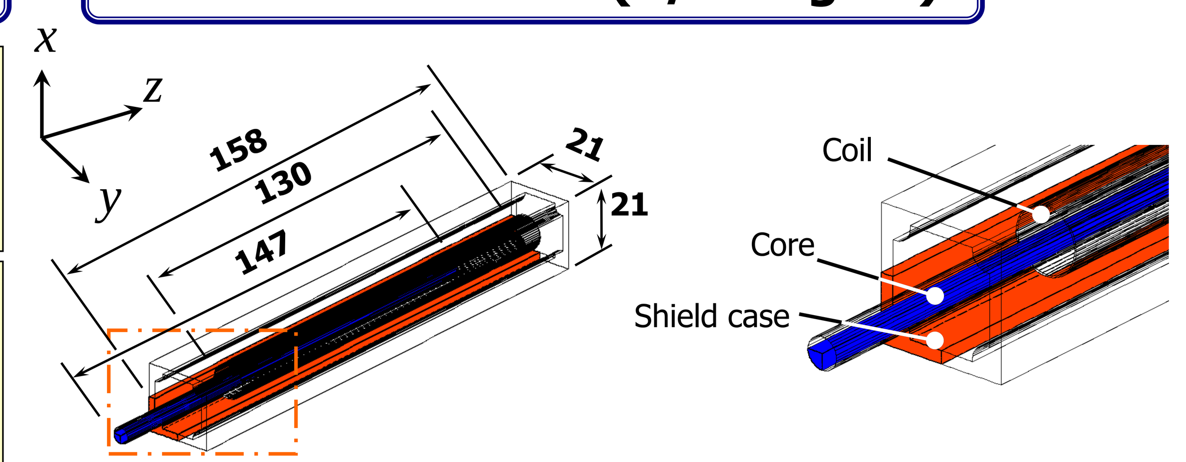
The analyzed results **show good agreement** with the measured ones

IMPEDANCE CHARACTERISTIC ANALYSIS

PROTOTYPE



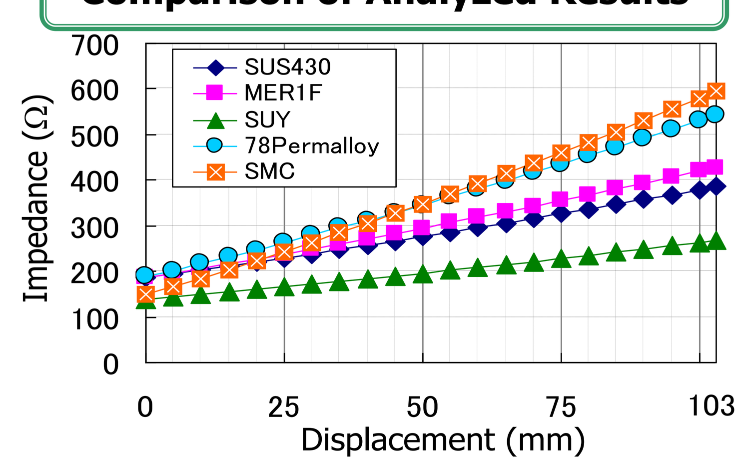
ANALYZED MODEL (1/4 Region)



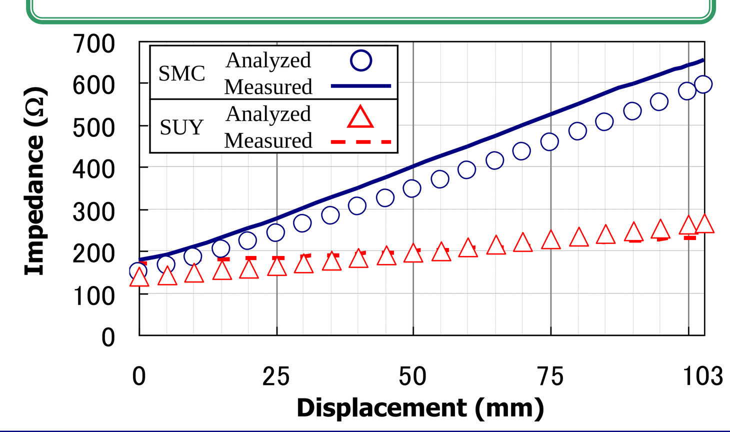
	Material	Conductivity σ (S/m)	Relative permeability μ_s
Shield case	Aluminum	3.4×10^7	1
Coil	Copper	5.8×10^7	1
Core	Used material properties of BLOCK		

ANALYZED RESULTS of IMPEDANCE CHARACTERISTICS

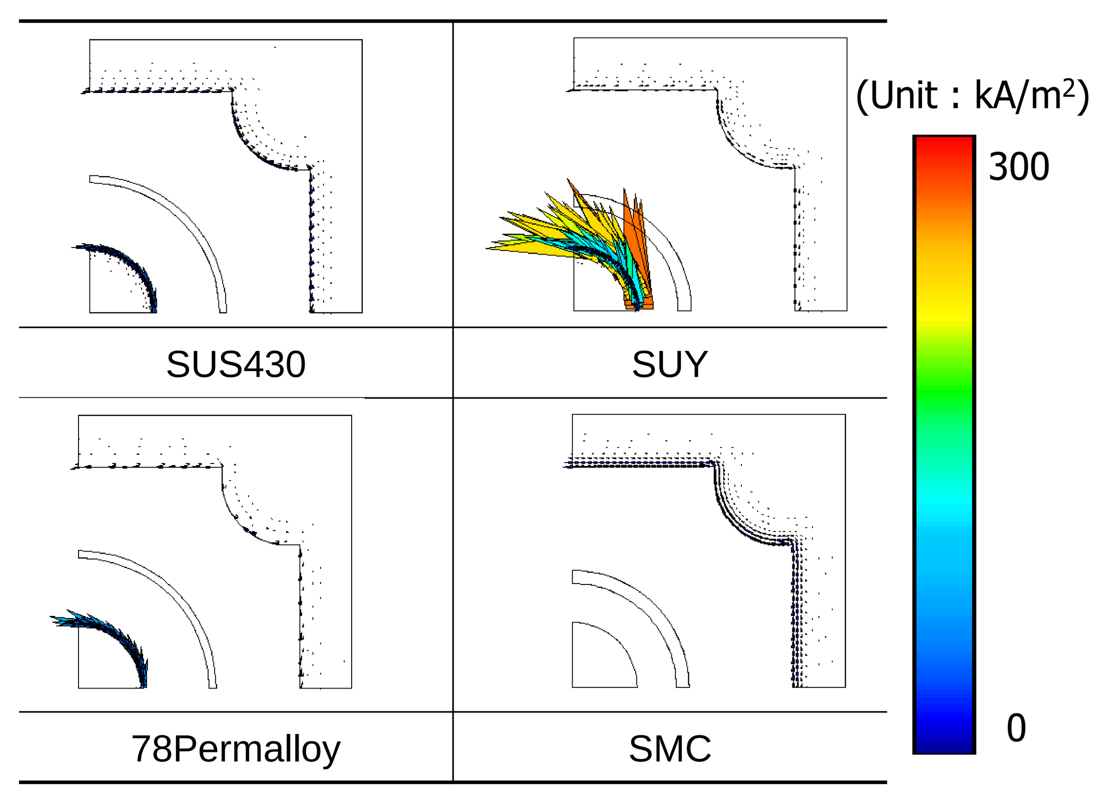
Comparison of Analyzed Results



Verification with Measurements



Eddy Current Density Distribution of Core (Max)



DISCRETIZATION DATA and CPU TIME

Intel Pentium IV 2.83GHz, 8.0G Memory RAM
Average Analyzed Time of Each Displacement

	SUS430	MER1F	SUY	78Permalloy	SMC
Number of Elements	2,360,484	2,874,564	2,911,692	5,242,188	2,064,888
Number of Nodes	408,690	495,686	502,139	894,338	357,783
CPU Time (Hours)#	3	5.5	6	39	3

The analyzed results of SMC entirely show good agreement with the measurement, even though maximum error is approximately 9% at maximum displacement.
On the other hand, the analyzed results of SUY shows maximum error about 16% at maximum displacement by comparison with the measurement.

CONCLUSION

We evaluated the effect of core materials on impedance characteristics by means of 3-D finite element method (FEM), which taken into account the complex permeability. The validity of the computation is verified by the comparison with the measurement of a prototype. Furthermore, suitable core material for a position sensor at high frequency is discussed.