Coupled Analysis of IPM(Interior Permanent Magnet) Motor

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Abstract :

Technology on how to raise the performance of home appliances as air conditioner, washing machine and the like, such as high efficiency, low vibration, low noise, etc., is making progress recently.

To model and simulate MCU/Inverter/Motor have been tried to apply into motor development as one of these energy-saving key technologies.

Wherein, with applying an IPM (Interior Permanent Magnet) Motor as a motif, to analyze and simulate with both MATLAB and JMAG-RT can obtain the same results with real object, i.e. the current is warped by means of current phase.

In consequence, an analyzing model which can simulate synthetically with considerations of motor magnetic circuit, inverter, and software implemented in MCU is obtained.

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JMAG Users Conference 2010
Coupled Analysis of an
IPM (Interior Permanent Magnet) Motor

Disclosure
Limited to the JMAG Users Conference
情報オーナー部門長(株)東芝　生産技術センター 制御技術研究センター長

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・Coupled Analysis of an IPM (Interior Permanent Magnet) Motor
  1. Background
  2. Configuring Simulations and Obtaining Results
・Efforts for Model Based Development
・Conclusion

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Background

Motors Used for Appliances

Interior fan motors
I: shortwave drives

I : Motor control systems

Air conditioners

Direct Drive motors for laundry machines
I: sinusoidal drive

Compressor motors
I: sinusoidal drive

Fan motors
I: shortwave drives

Compressor motors
I: sinusoidal drive

Exterior fan motors   Compressor motors
I: sinusoidal drive   I: sinusoidal drive

Laundry

Refrigerators

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Background

High Efficiency, Low Noise Appliances

Demands for appliance motors (vector control)

Compressor motors
Air conditioners

Laundry machines
DD motors

Compressors
Motor

Built-in laundry heat pumps

Improved performance for higher efficiency and lower noise are in demand.

Drive circuit and motor structure

Bilaterally affected

Microcomputer

S   N

Inverter   Motor
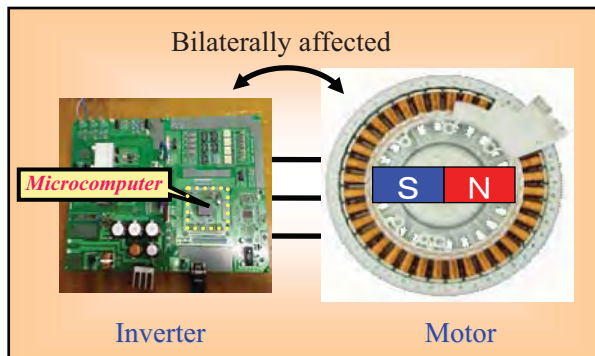
Model

Easier desktop testing reduces development lead times

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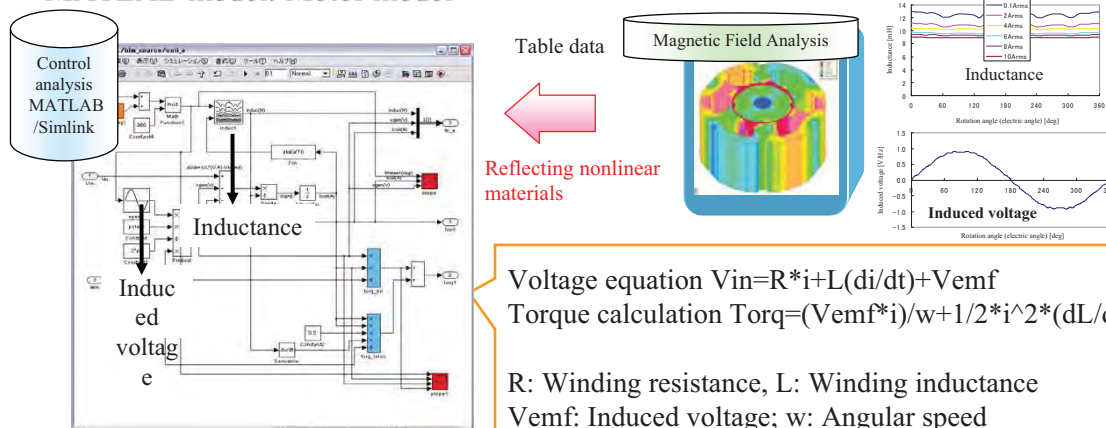

Background

Conventional Simulation Models

Challenges: Obtaining more detailed and accurate motor behavior for reinforced motor development is necessary in simulations.

Generating table data from motor constants obtained in magnetic field analysis (induced voltage, inductance), and then utilizing that data for numerical analysis of models.

MATLAB model: Motor model

Control analysis MATLAB /Simlink

Table data

Magnetic Field Analysis

Inductance

Induced voltage

Inductance

Reflecting nonlinear materials

Induced voltage

Voltage equation Vin=R*i+L(di/dt)+Vemf
Torque calculation Torq=(Vemf*i)/w+1/2*i^2*(dL/dθ)

R: Winding resistance, L: Winding inductance
Vemf: Induced voltage; w: Angular speed
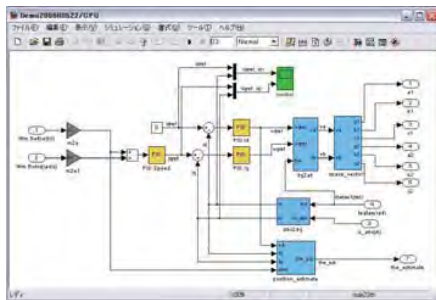
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Background

Structure of Microcomputer Models

Structure of microcomputers: Vector control software

Structure of MATLAB (vector control)
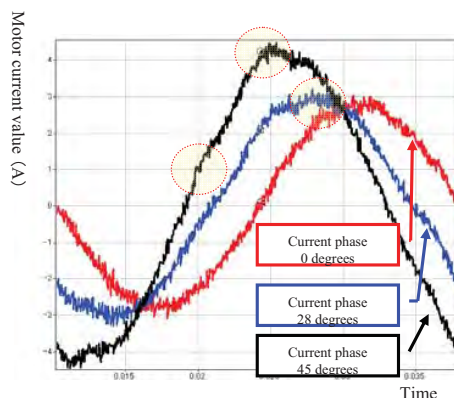

Consistency of programs in actual microcomputers
・Discrete systems：PWM period
・ Unifying control gain: Clarifying the unit system
・PWMOutput: Space vector method
・Clarifying the order control is executed
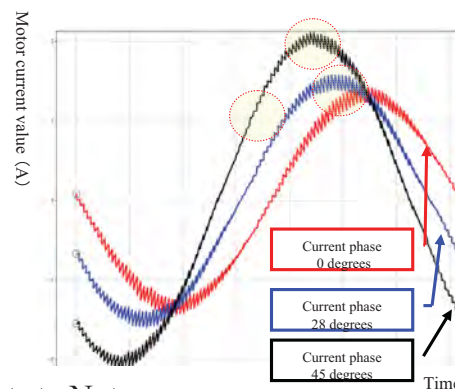・Dead time

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Background

Results from Conventional Simulations

Motor current waveform: Actual

Motor current value (A)

Current phase
0 degrees

Current phase
28 degrees

Current phase
45 degrees

Time

Motor current waveform: Simulation

Motor current value (A)

Current phase
0 degrees

Current phase
28 degrees

Current phase
45 degrees

Time

Points to Note

→ The current becomes more distorted as the current phase proceeds

→ Distorted current caused by variations in the current phase cannot be reproduced.

The distortion fo the current is not expressed.
→ There are no measures to increase efficiency and lower vibrations

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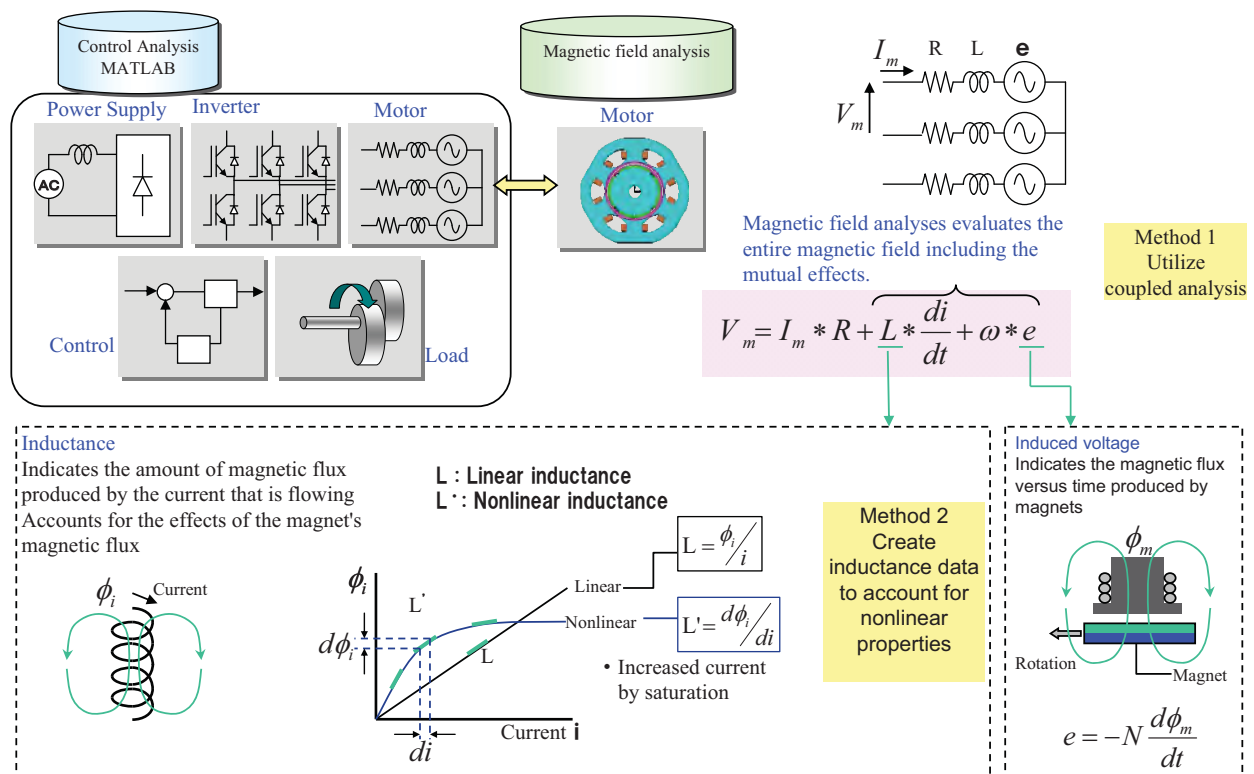・Coupled Analysis of an IPM (Interior Permanent Magnet) Motor
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Configuring Simulations and Obtaining Results

Direct Coupled Analysis of Circuits/Magnetic Fields

Control Analysis MATLAB

Power Supply   Inverter   Motor

AC

Control   Load

Magnetic field analysis

Motor

Magnetic field analyses evaluates the entire magnetic field including the mutual effects.

$$V_m = I_m * R + L * \frac{di}{dt} + \omega * e$$

Method 1
Utilize coupled analysis

Inductance
Indicates the amount of magnetic flux produced by the current that is flowing
Accounts for the effects of the magnet's magnetic flux

ϕ_i Current

L : Linear inductance
L˙: Nonlinear inductance

ϕ_i

$d\phi_i$

L˙

L

Linear

Nonlinear

$L = \phi_i / i$

$L' = d\phi_i / di$

• Increased current by saturation

di Current **i**

Method 2
Create inductance data to account for nonlinear properties

Induced voltage
Indicates the magnetic flux versus time produced by magnets

ϕ_m

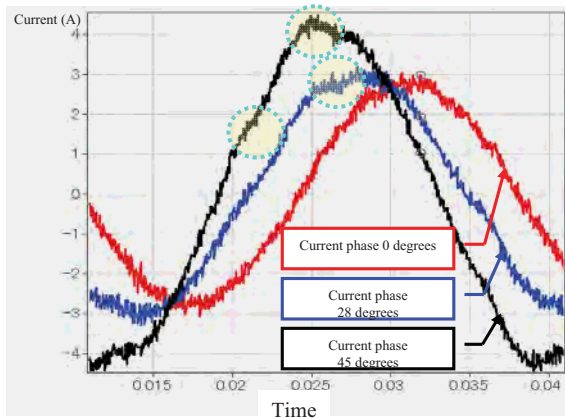Rotation

Magnet

$$e = -N \frac{d\phi_m}{dt}$$

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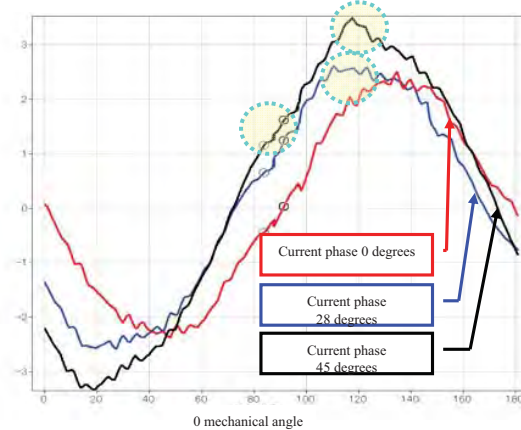Leading Innovation >>> ·

Configuring Simulations and Obtaining Results
Direct Couple Circuit/Magnetic Field Analysis

Actual: Motor current waveform

Directed coupled analysis between magnetic field analysis software and MATLAB: Motor current waveform

The current distortion caused by the current phase can be reproduced.
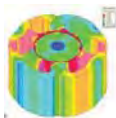・Magnetic field analysis simulations
  Requires time. Actual time:2 Sec --> Analysis time 30 hr.

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Configuring Simulations and Obtaining Results
Coupled Analysis Using JMAG-RT

JMAG-RT

Analysis using the finite element method

Reflects geometry and nonlinear properties of materials

Inductance data by current phase (0 degrees to 360 degrees)

Lq by angle

Ld by angle

Currents Phase 0 degrees
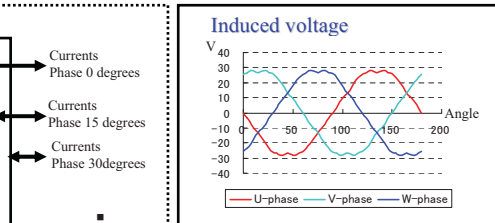Currents Phase 15 degrees
Currents Phase 30degrees

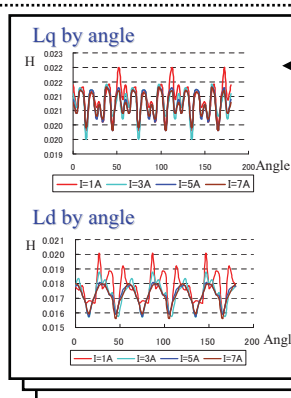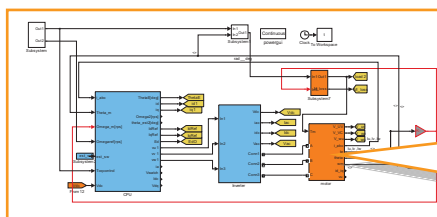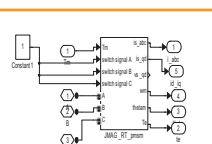Currents Phase 360degrees

Induced voltage

Table data
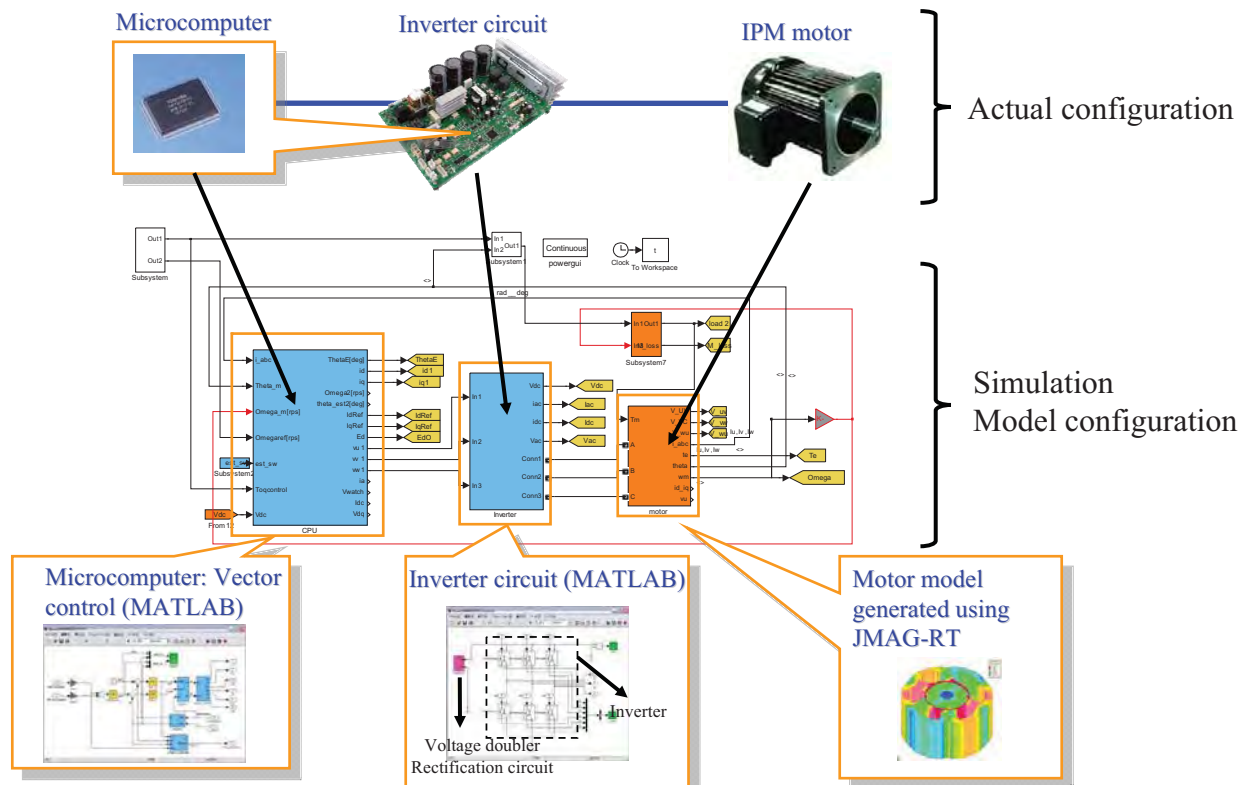
MATLAB model

Motor model

Motor model to run analysis in control simulations

A coupled analysis can be performed using JMAG-RT models which includes characters such as torque by current and phase, flux linkage, and inductance and MATLAB

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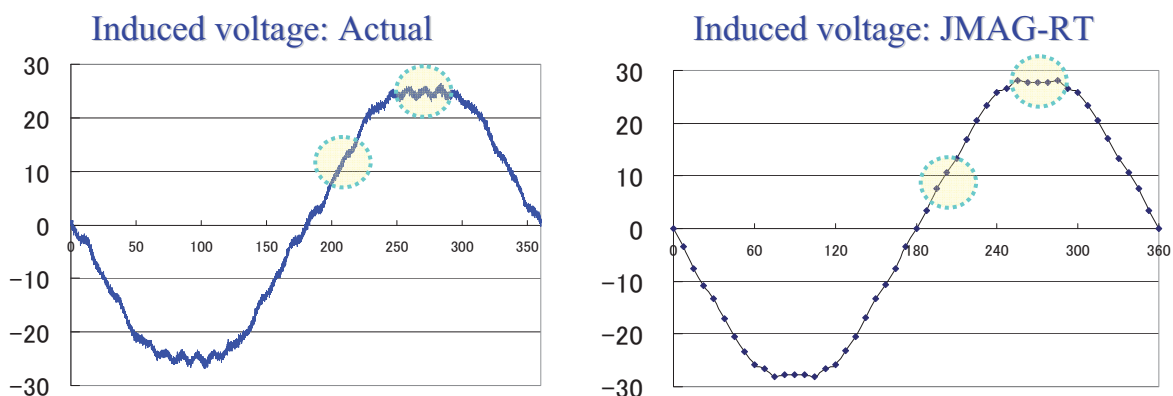*Configuring Simulations and Obtaining Results*

Simulation Configuration

Microcomputer   Inverter circuit   IPM motor

Actual configuration

Simulation
Model configuration

Microcomputer: Vector
control (MATLAB)

Inverter circuit (MATLAB)

Voltage doubler
Rectification circuit

Inverter

Motor model
generated using
JMAG-RT

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Configuring Simulations and Obtaining Results

Motor Characteristics using JMAG-RT

Comparing the induced voltage of the actual motor
and the and JMAG-RT model

Induced voltage: Actual   Induced voltage: JMAG-RT

Points to Note

Analysis results are almost the same

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Configuring Simulations and Obtaining Results
Confirming Reproduction on the Actual Motor

Actual motor current waveform

Coupled JMAG-RT and MATLAB analysis: Motor current waveform
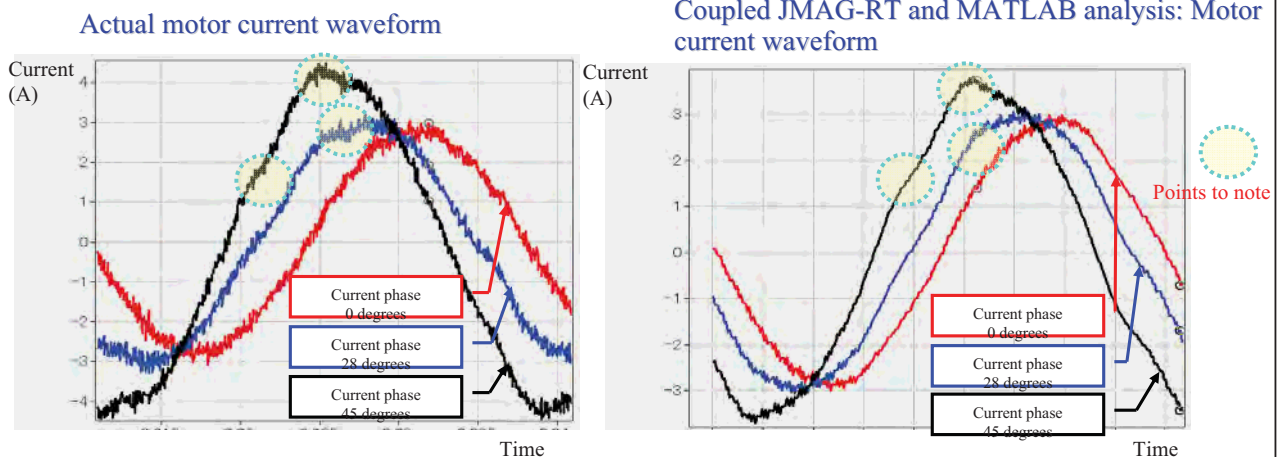
The correlation between the variations of the current phase and the current waveform are obtained

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Configuring Simulations and Obtaining Results
Time Required for Analyses

Analysis Time and Analysis Accuracy

	Motor model Time setting analysis	Analysis Time	TOTAL Analysis time （10 times）	Analysis accuracy
MATLAB	-	O 0.5 hr.	5 hr.	△
MATLAB＋ Magnetic field analysis software (direct coupled analysis)	—	× 30 hr.	300 hr.	O
JMAG-RT ＋MATLAB	10 hr.	O 0.5 hr.	10 hr.＋5 hr.	O

Improve analysis accuracy using the same amount of time as MATLAB
(Time is required to generate the motor model)

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Model based development

Future: Model Based Development

Model based development (image)

Virtual

Motor model   Control equipment model

Device for control   Real   Actual control equipment

・Model the control equipment and control target features using CAE tools

・Improve development efficiency and quality by actively utilizing models

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Model based development

Structure for Investigating Motors and Inverters

Virtual

microcomputer model

Inverter model
(IGBT, converters, etc.)

Motor model
(JMAG-RT)

Virtual evaluation

Real time
simulator

Real

Inverter circuit　　　　IPM motor

Microcomputer

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Model based development

Variations in Development after Implementing MDB (Tentative)

Present development　　　　　　Development after implementing MBD

Real

For control
(motor)

Actual control equipment
(motor + microcomputer)

Virtual

Control target model
(motor + inverter)

Real

Actual control equipment
(microcomputer)

・Motor design
・Motor production
・Inverter production
・Create software
・Debug software
・Power supply devices
・Evaluate

Challenges
・Cannot evaluate
　without the motor
・Debugging software
　takes time
・Testing high voltage

・Motor design
・Motor production
・Inverter
production
・Create software
・Debug software
・Power supply devices
・Evaluate

Effects
・No prototype development
・Reduced development
lead time
・Optimization design
・Debug software
Higher efficiency
・Safer evaluation without
needing high voltages

Evaluation and software development is simplified using virtual systems.
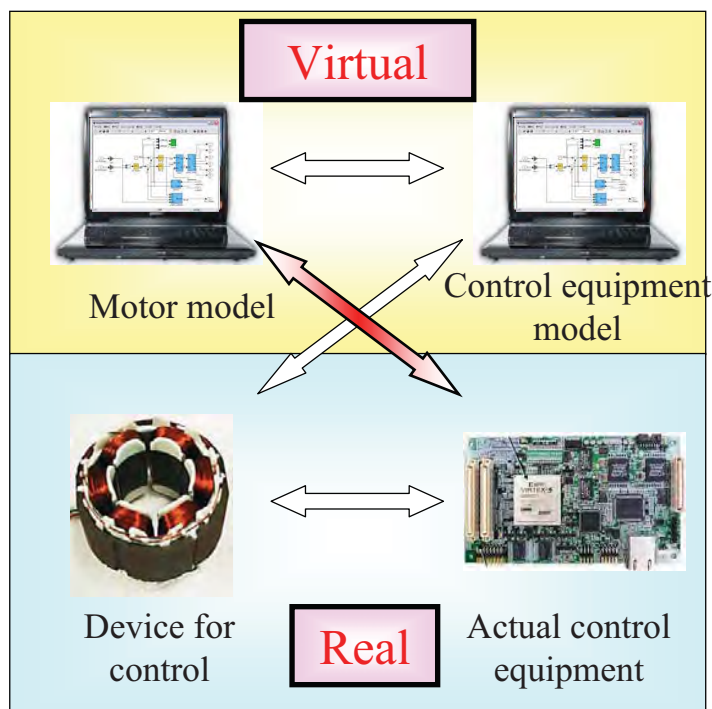
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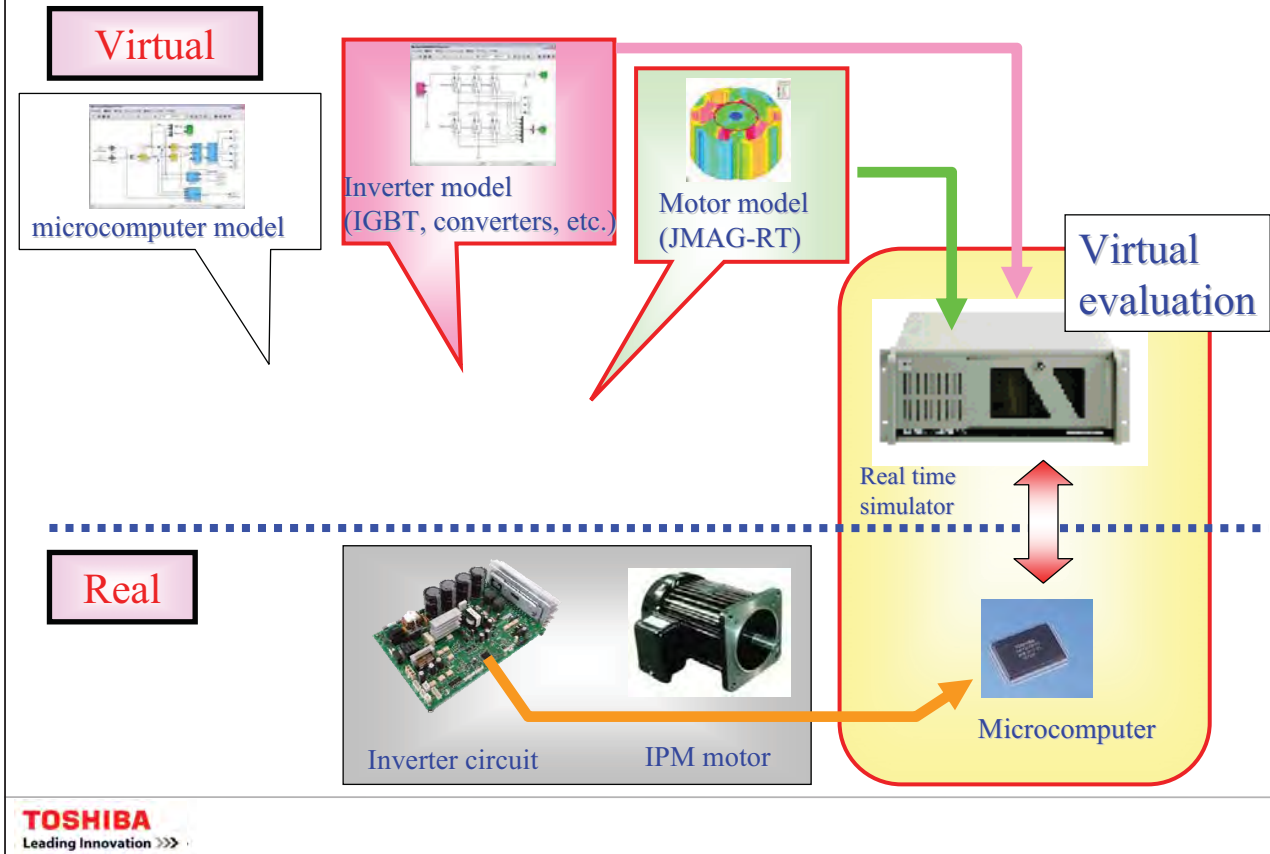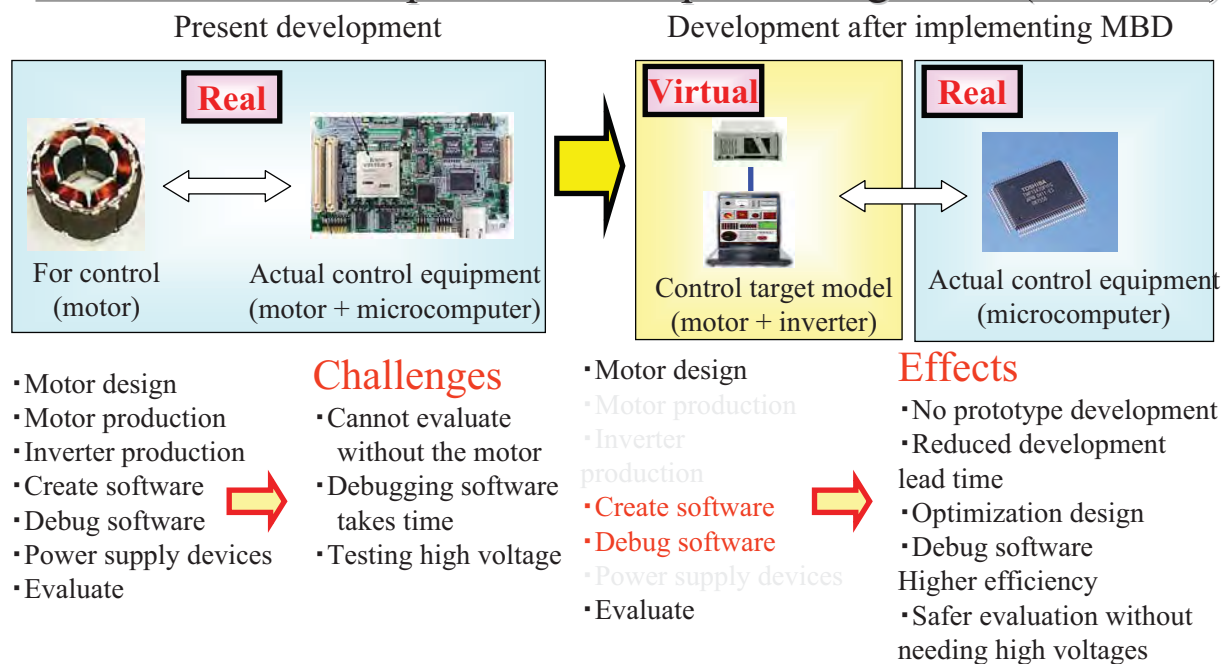・Conclusion

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Conclusion

Conclusion

1. An analysis model that can perform a simulation integrating the software for the magnetic circuit, inverter, and microcomputer of a motor is obtained by running a MATLAB and JMAG-RT coupled analysis.

2. A simulation more accurately reproducing the actual motor characteristics can be achieved by accounting for the material properties and geometry as well as the nonlinear characteristics of the motor.

3. In the future, model based development using JMAG-RT models is planned.

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14 - 13