Developing Motor Drive Systems Using JMAG-RT

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Abstract :
In recent years for motor drive systems, the motor design and the control development need to be undertaken simultaneously to achieve higher quality under even stricter development schedules.
This presentation introduces how to create highly accurate motor models using JMAG-RT for new motor designs, run motor simulations linking to the motor control, and then use the results that are obtained to provide feedback to the motor design and the control development.
In addition, Hardware in the Loop Simulation (HILS) with JMAG-RT built-in is examined as a real time simulator and an example linking our drive products with highly accurate motor models is also introduced.

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JMAG Users Conference 2010

JMAG-RTを活用したモータ駆動系開発の事例紹介

Developing Motor Drive Systems Using JMAG-RT

三菱電機株式会社 名古屋製作所

原川 雅哉

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Mitsubishi Electric Corporation Nagoya Works

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■ Contents

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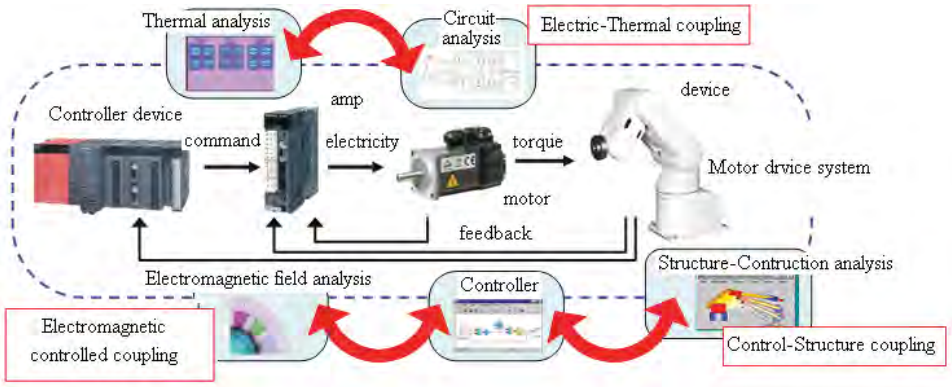
■ Background

Mitsubishi Electric Corporation Nagoya Works develops and manufactures factory automation products (drive products/controllers/mechatronics).

Motor drive systems combine various technology and phenomena which make couple analysis indispensable at the development and design stage.



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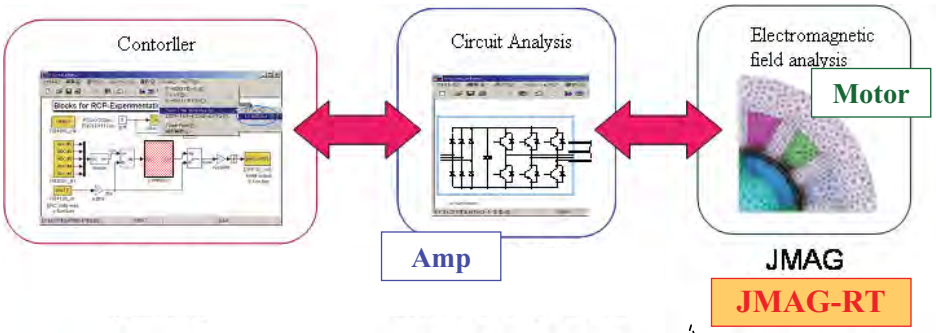
■ Background

This presentation introduces coupled analysis for control ⇔ circuit (amp) ⇔ electromagnetic fields (motor).



JMAG-RT is a finite element analysis tool for electromagnetic field analysis providing:

- Nonlinear magnetization properties of materials
- Current dependency of inductance
- Geometric dependency of torque

which generates **"highly accurate motor models"** that run internally in MATLAB or PSIM

* Motor models created from equations that do not have nonlinear characteristics are called "formula models" in this presentation.

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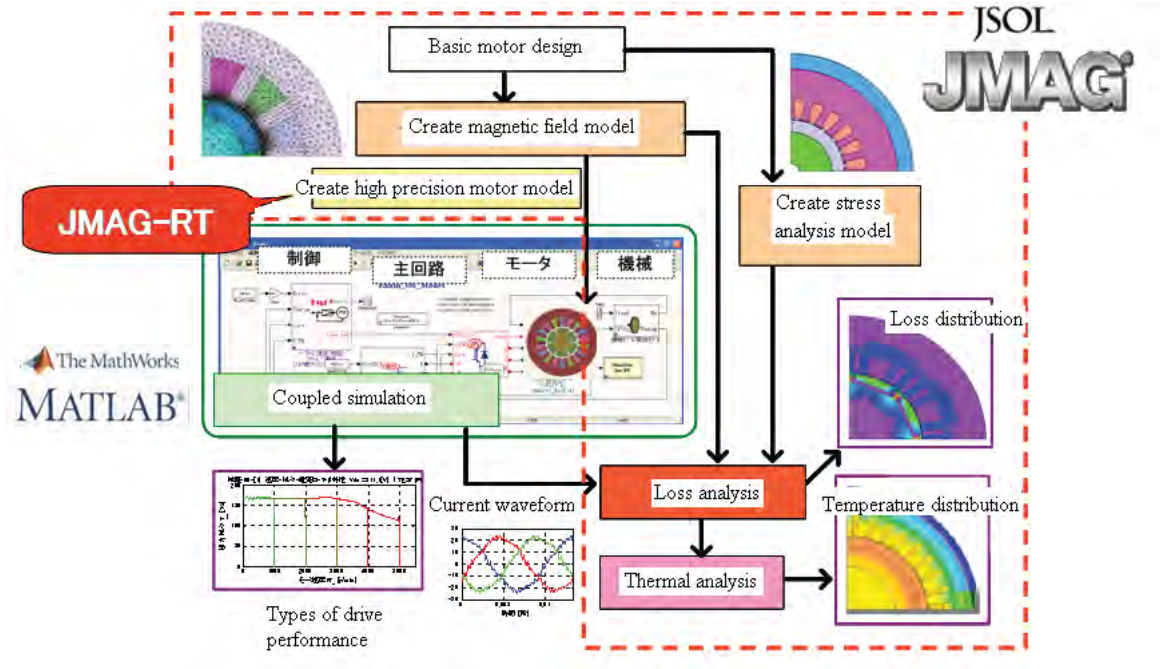
■ Flow of JMAG-RT Coupled Analysis



Various drive characteristics such as motor loss/temperature can be obtained by combining the control.

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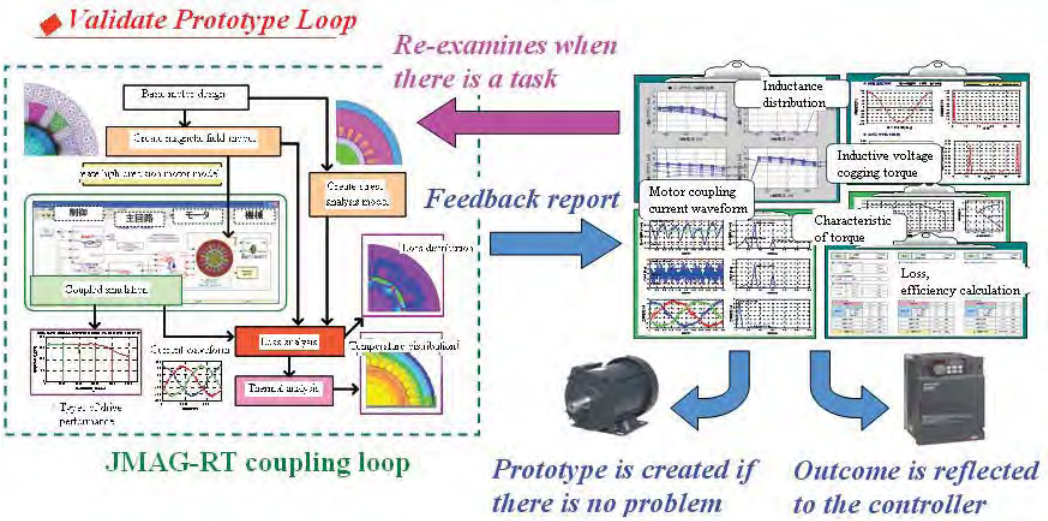
■ Benefits of JMAG-RT Coupled Analysis

(1) The number of prototypes can be drastically reduced because motor characteristics can be obtained without prototypes.

(2) Characteristics closer to actual motors can be obtained using analysis combining amps (control)

(3) The results provide feedback not only to the motor design but also the amp (control) development.

Improved performance and shorter development periods can be realized for total motor drive systems.



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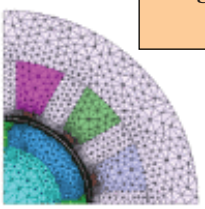
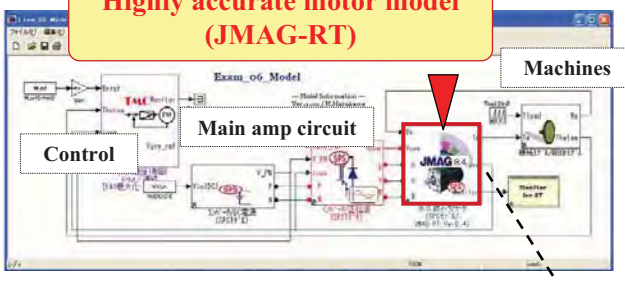
■ Creating Highly Accurate Motor Models



Magnetic field analysis model (JMAG)

Highly accurate motor models including nonlinear elements can be automatically generated based on the magnetic field analysis results.

Highly accurate motor model (JMAG-RT)



Highly accurate simulations run using highly accurate motor models and links to control, circuits, and machines

MATLAB Linked Simulation (Simulink/SimPowerSystems)

- Nonlinear magnetization properties of materials
- Current dependency of inductance
- Geometric dependency of torque

are taken into account

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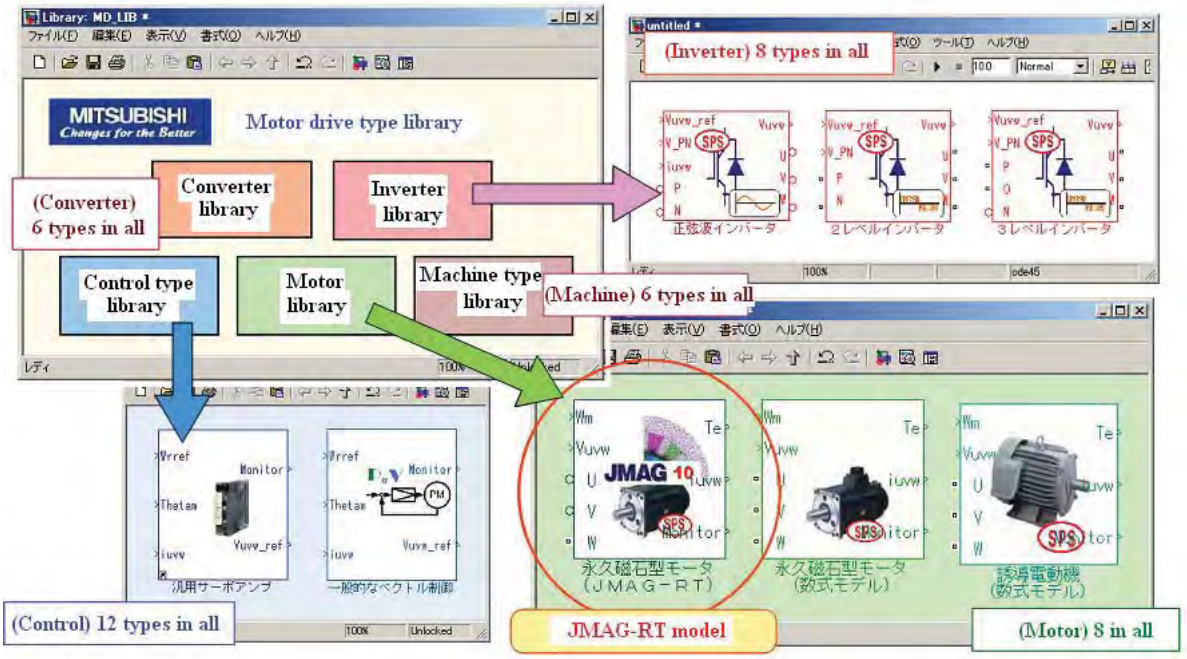
■ Motor Drive System Library (Mitsubishi Original)

Original simulation blocks are available so that linked analyses can be performed with ease.



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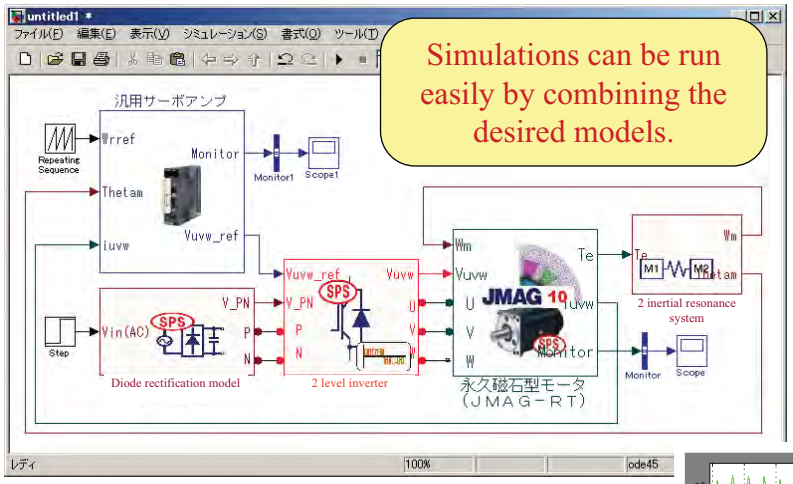
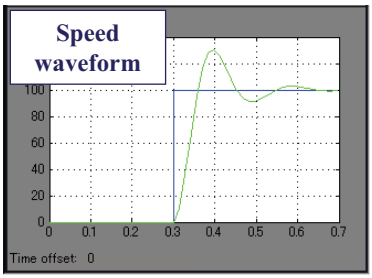
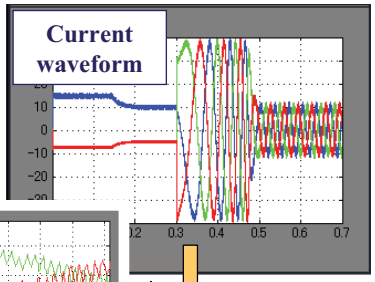
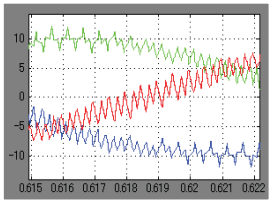
■ Regarding Linked Simulations

Simulations can be run by combining the desired blocks from the motor drive system library.









Enlarged current ripple

Linked simulations can now be run simply by designers with little control experience, such as motor designers.

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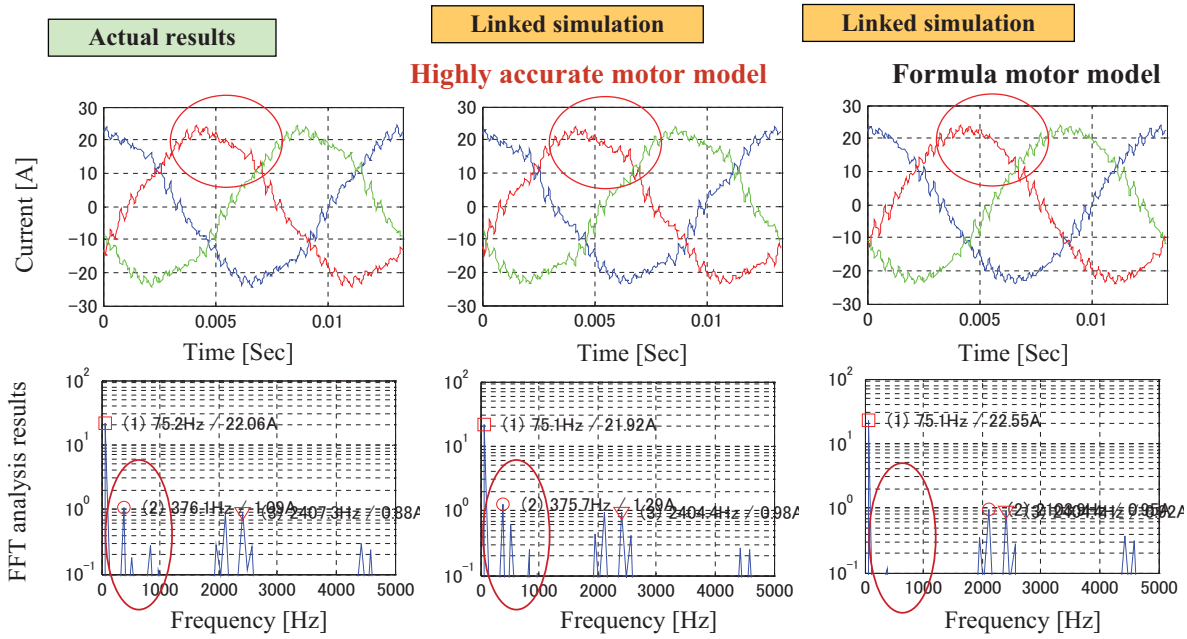
[Analysis Example] Comparing Current Waveforms

Motor for analysis（7.5 [kW]）; Speed＝1500 [r/min]
Torque ＝20 [Nm]; PWM Carrier fc＝2.25 [kHz]



A large difference can be seen in the 5th, 7th, and 11th order components of the fundamental wave.

→ The highly accurate motor model obtains a current waveform extremely close to the actual waveform.

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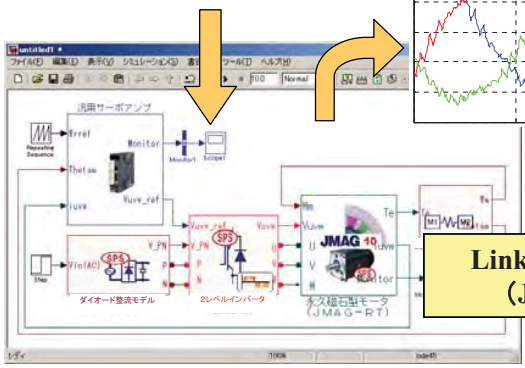
■ Calculating Motor Loss

Various drive conditions

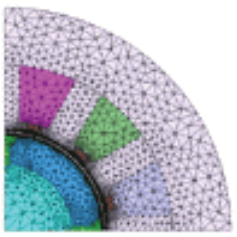
- Motor speed
- Load torque
- PWM carrier frequency, etc.

Current waveform

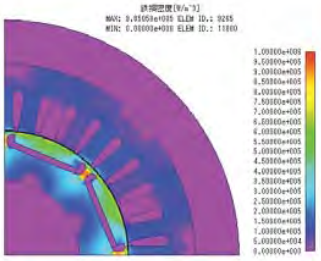


Linked simulation (JMAG-RT)

Magnetic field analysis embedding current waveforms（JMAG）



JMAG loss Calculation tool



The loss of a motor can be obtained accurately by running a magnetic field analysis using current waveforms obtained from linked simulations.

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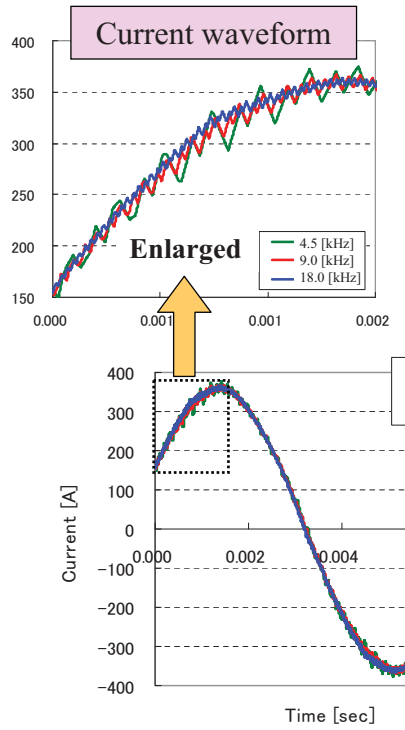
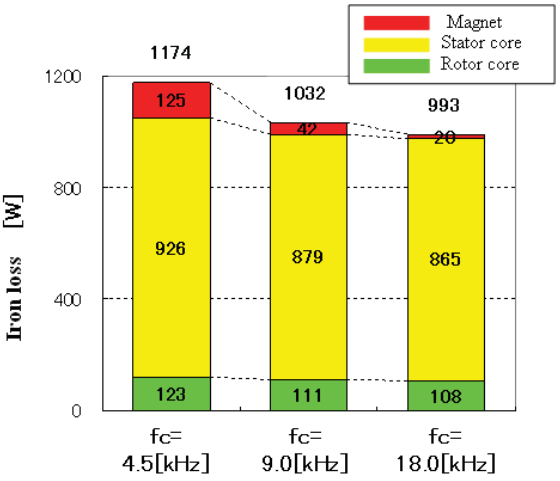
(Example of large capacity motors)

[Analysis Example] Comparing Loss Using PWM Carrier Frequencies



The variations of the current waveform and iron loss can be analyzed by changing the PWM carrier frequency.

Iron loss analysis results



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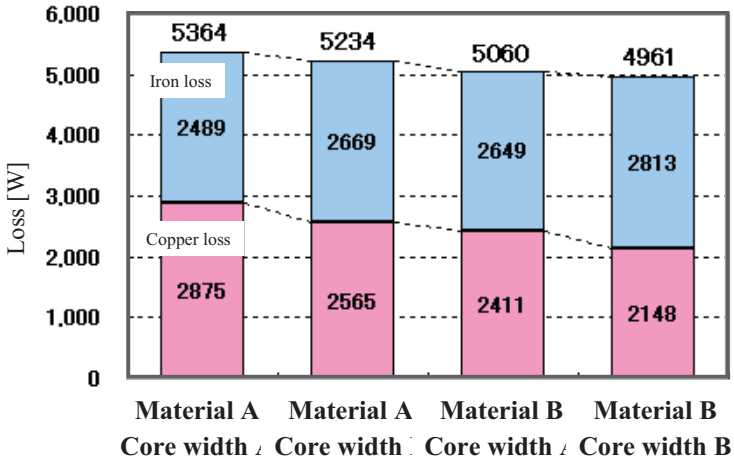
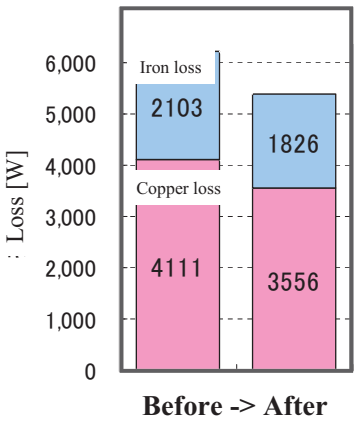
(Example of large capacity motors)

[Analysis Example] Comparing Loss by Changing Analysis Conditions

The optimal motor design can be examined while modifying magnet materials and dimensions.
Furthermore, the combined motor characteristics can be understood, such as driving the motor with the most efficient control.





Most efficient control

Enhanced performance by combining the motor and control

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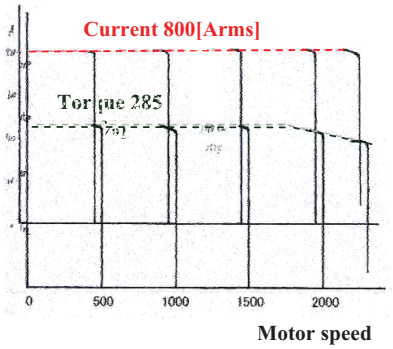
[Analysis Example] Speed - Torque - Current Characteristics

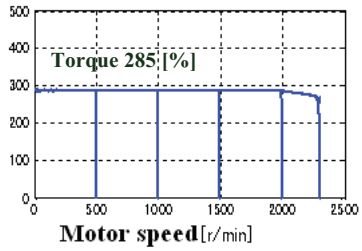
(Example of large capacity motors)

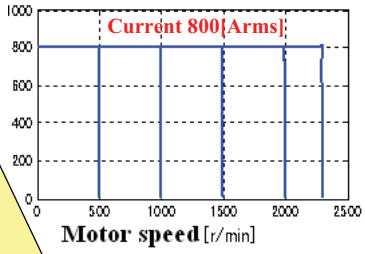
Actual results



Linked simulation

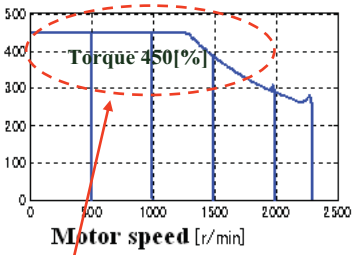
Highly accurate motor model

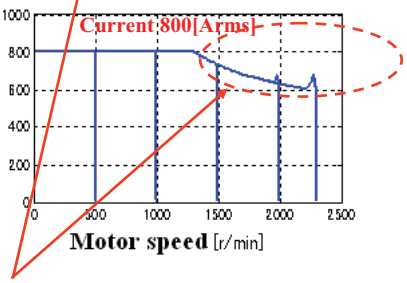




Linked simulation

Formula motor model





The highly accurate motor model is advantageous because the torque characteristics change drastically with the magnetic saturation for IPM motors.

The reluctance torque is over-calculated because magnetic saturation is not taken into account. The current values don't match.

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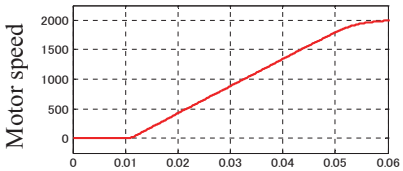
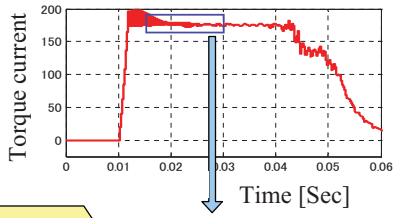
[Analysis Example] Regarding the Gain of the Current Control System

Linked simulation

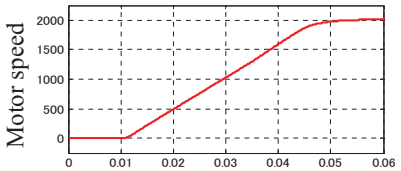
Highly accurate motor model

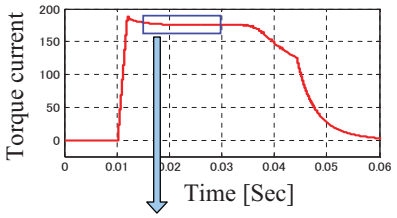




Linked simulation

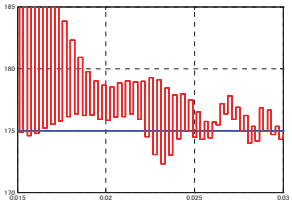
Formula motor model

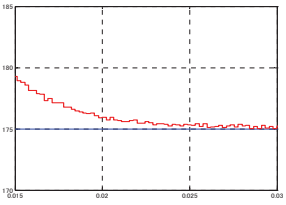




The optimal gain of the current control system can now be examined in advance.

Vibration phenomena caused by carrier frequency components when the gain of the current control is to high can be reproduced just as that of the actual motor by using highly accurate motor models.





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■ Conclusion for JMAG-RT Coupled Analysis

Analysis	Loss Analysis			Control speculation	
	Loss derived from sine wave	Loss derived from PWM inverter	Loss derived from combination of highest efficiency	Loss derived from characteristic of torque speed	Speculation of control gain from optimum current
Previous motor analysis	○	×	×	×	×
After coupling simulation by JMAG-RT is implemented	○	○	○	○	○

Improved performance and shorter development periods for total motor drive systems are advancing through coupled analysis utilizing JMAG-RT

■ Request to JSOL

A similar development environment for electric induction machines is needed.

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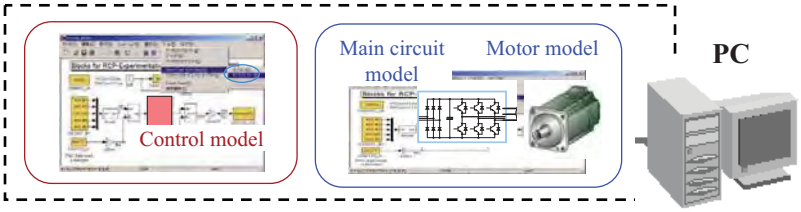
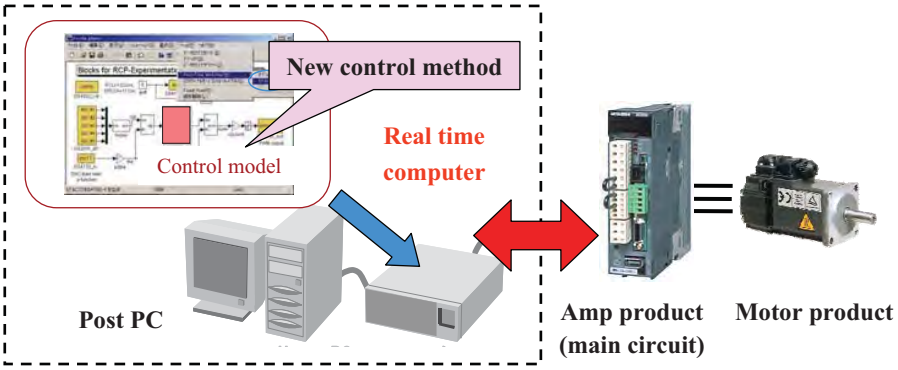
■ Regarding Model Based Development Methods

(1) Offline simulation



(2) RCP evaluation (Rapid Control Prototyping)

・In a MATLAB/Simulink control block, the actual motor can be driven and the commands of the real time controller can be generated automatically.



☆ Method for examining control models (new method) at an early stage by driving amps/motor products.

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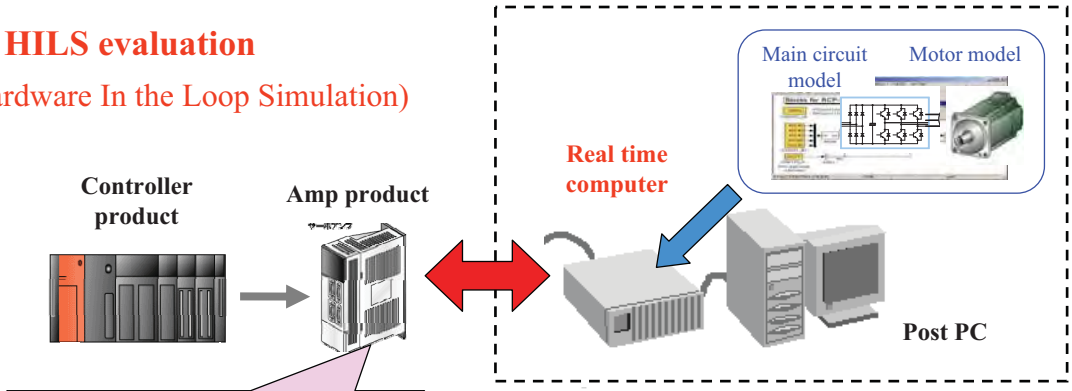
■ Regarding Model Based Development Methods

(3) HILS evaluation

(Hardware In the Loop Simulation)



The S/W debugging for new products can be utilized

・The model is generated with the MATLAB/Simulink control block and MATLAB/SimPowerSystems circuit.

・The commands of the real time computer are automatically generated and executed.

☆ The virtual circuit + motor (+machines) are examined using the amp product.

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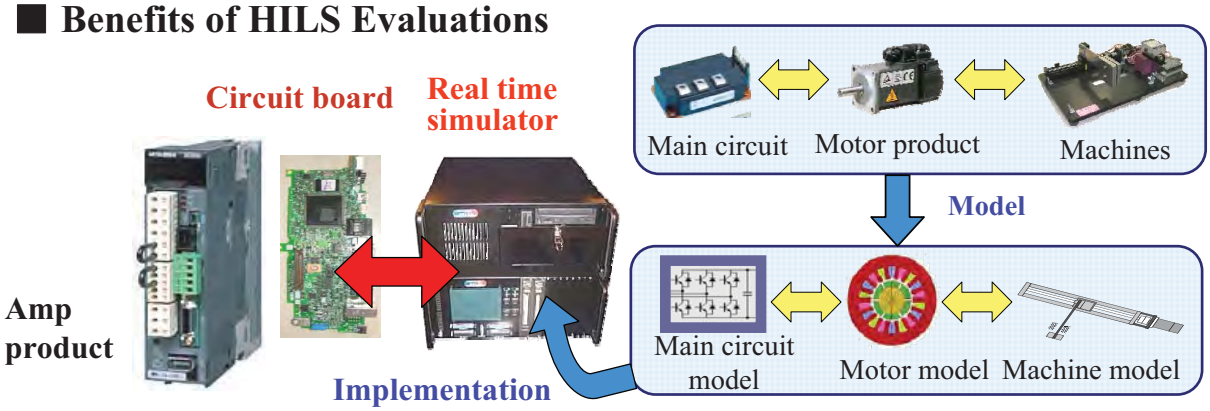
■ Benefits of HILS Evaluations



- Evaluation using actual products (control) can be performed before a motor prototype is build.
- Very effective for actual evaluations that are not easy to perform, such as large capacity motors or customer devices.

(Recently, actual devices are hard to evaluate because of size)

→ Amp product S/W (control) evaluation (debugging) is more efficient

HILS is flexible for examining actual devices, therefore, it is a powerful tool for product development.

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■ HILS Devices Used

Real time simulator [RT-LAB]
(Canada - OPAL-RT)

OPAL-RT RT-LAB

A rapid calculation of a maximum 8 [μ sec] periods is possible
* A calculation with a 1 to 2 [μ sec] period can be attained by implementing a model in FPGA

Analog input/output 16ch
Digital input/output 32ch
Optical (PWM signal) input/output 16ch

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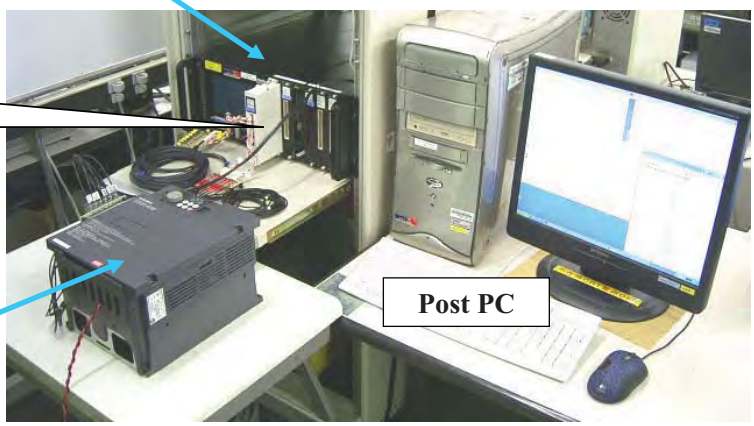
Amp product
(Mitsubishi)



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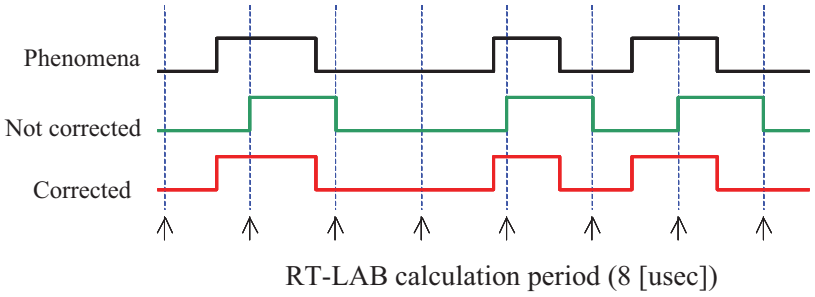
■ Features of RT-LAB

Time Stamping Technique

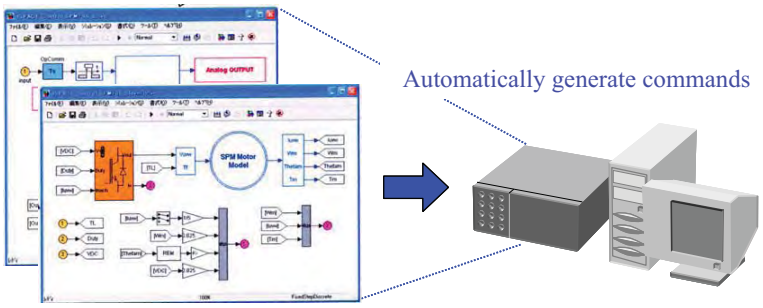
Xilinx FPGA
(100[MHz]Clock) is used →
10 [nsec]
time resolution



The time stamping technique is compression technology from OPAL-RT that can accurately reproduce switching occurring in the calculation period.

The program can be included in MATLAB/Simlink and the commands are automatically generated.

MATLAB/SimPower Systems programs can also be implemented



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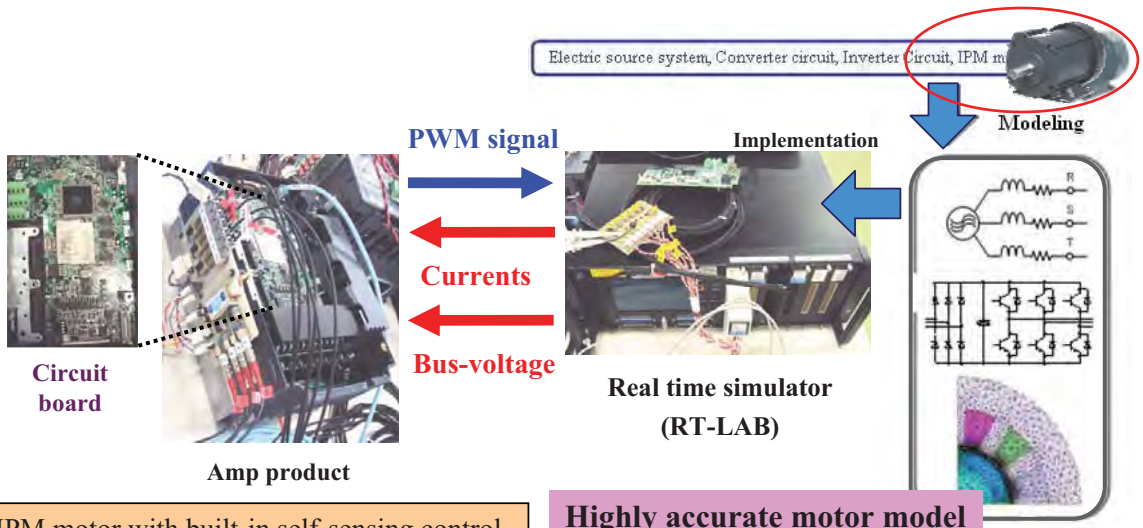
■ Configuration of HILS Using JMAG-RT



IPM motor with built-in self-sensing control

Highly accurate motor model (JMAG-RT)

HILS implements the actual motor drive products and the highly accurate motor model (real time simulation).

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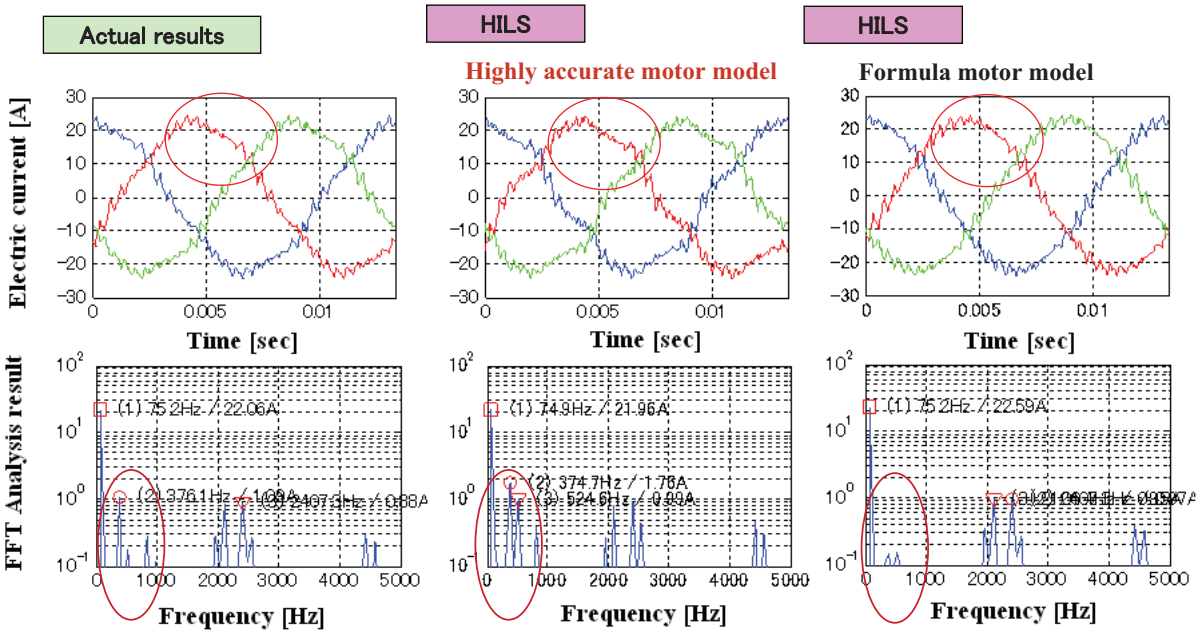
[Analysis Example] Comparing Current Waveforms

Motor for analysis (7.5 [kW]); Speed=1500 [r/min]
Torque =20 [Nm]; PWM Carrier fc=2.25 [kHz]



Current waveforms matching the prototype can be obtained in the HILS evaluation by using a highly accurate motor model.

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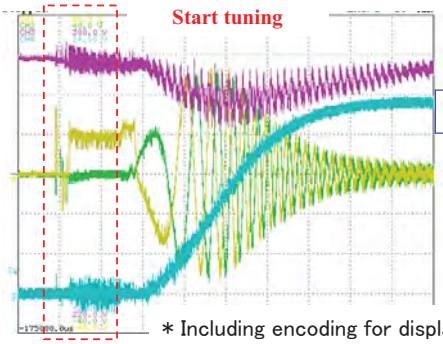
【Analysis Example】 Operating Self-sensing Control

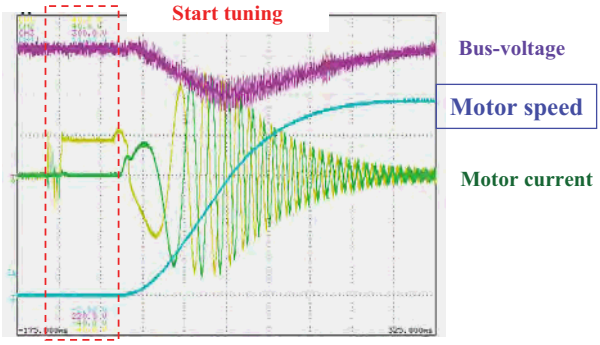
If HILS uses a highly accurate motor model, results the same as the actual motor can be obtained.

Actual results

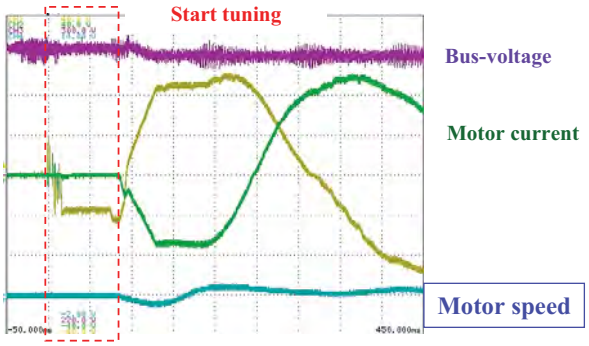


* Including encoding for display
(Actually driven by speed self-sensing control)

HILS **Highly accurate motor model**



HILS **Formula motor model**



The motor cannot accelerate because the estimated position of the magnetic poles is incorrect.

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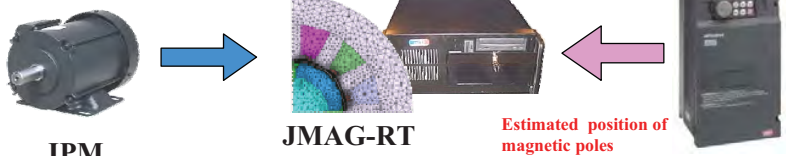
■ Magnetic Saturation Characteristics of an IPM Motor



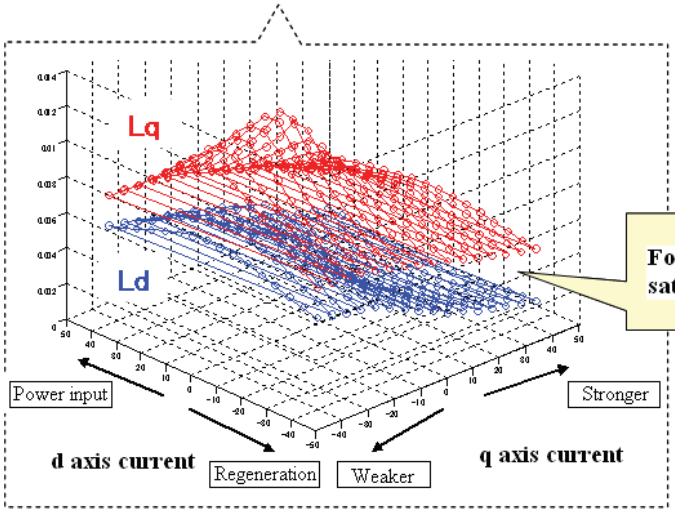
IPM motor

JMAG-RT
Highly accurate motor model

Estimated position of magnetic poles

In self-sensing control, the estimated position of the magnetic poles uses the magnetic saturation characteristics of a motor.

JMAG-RT's highly accurate motor model is effective



Four-quadrant dq positions for magnetic saturation characteristic is required

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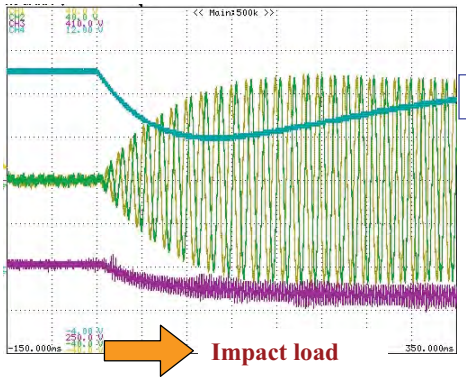
【Analysis Example】Regarding Various Drive Modes

◆Impact load drive

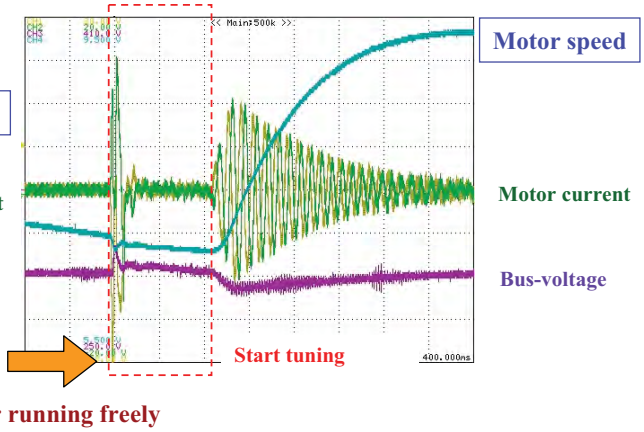
HILS



The decline in speed and bus-voltage can be reproduced with an impact load

◆Instantaneous start/stop functions

HILS



A function for restart by matching motor speed even when the motor is running freely because of a sudden stop.

HILS can include free running motors

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■ Contents

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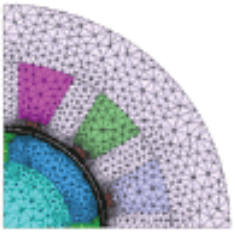
■ Conclusion



[Utilizing JMAG-RT's Highly Accurate Motor Models]

(1) Motor characteristics close to actual motors can be obtained using linked simulations

→ Understand motor characteristics without prototypes

(2) A mutual link between motor and control can be used at the development stage

→ Improve performance and reduce development periods as total drive systems

(3) Self-sensing control which is greatly affected by motor constants can be evaluated in HILS

→ Further expands HILS effectively

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Thank you for coming.