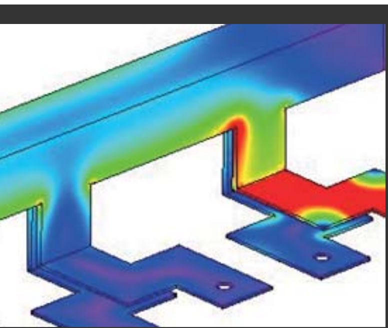
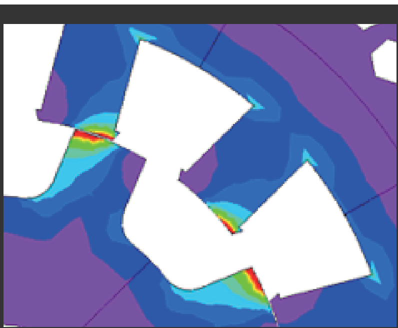
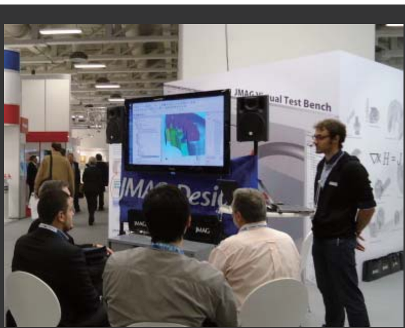
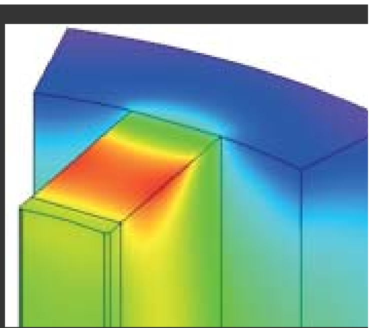
Simulation Technology for Electromechanical Design

JMAG®

JMAG Newsletter

March, 2014

Simulation Technology for Electromechanical Design

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JMAG Newsletter: Highlights of the March Issue

We are pleased to present you with the March issue of the JMAG Newsletter.

In this issue's Implementing JMAG, we will look at John Deere who has led the world in the field of agicultural equipment and construction apparatus. We interviewed him to hear of his reason in implementing JMAG and of his successful results. I will introduce how JMAG is being used in John Deere'selectrification project.

In "Product Report". we will introduce the performance of JMAG's incredibly fast high parallel solver and GPU solver. As we are continually developing on increasing the speed of JMAG's solver, this article will be of interest to those who wish to quickly calculate large models.

In addition, useful functions are constantly being added to our motor design tool, JMAG-Express. We will introduce motor design examples that make full use of the unique features in JMAG-Express so please use it in increasing the efficiency of your motor design work.

"Solutions" talks of motor thermal design. As the first issue, we have put focus on modeling technology in thermal analysis, and will introduce modeling of winding and laminated steel.

In "JSOL Activity Report", we will introduce our involvement with iron loss. Among the few issues, we will introduce iron loss calculation of direct current bias magnetism that is difficult in the application of conventional Steinmetz's empirical law and necessary material data, as well as initiations with measurement.

JMAG Newsletter is naturally for those already using JMAG, as well as intended for those who have yet to use JMAG or have only recently started doing so. By all means, takes this chance to introduce it to someone nearby.

This edition of the JMAG Newsletter is packed with useful content. We hope you enjoy it.

JSOL Corporation

Electromagnetic Engineering Department, Engineering Technology Division

Implementing JMAG

John Deere

Virtual Prototyping in Developing Next Generation Heavy Equipment

In this issue we'll learn a little more about John Deere. John Deere has been aggressively pursuing electrification of their vehicles to increase productivity and reduce operating cost. Electrification projects range from adding small electrical motors to improve cabin comfort to creating a hybrid drive system by incorporating traction motors. There are many benefits to electrifying heavy machinery. Besides the obvious reduction in fuel consumption and improvement in ride quality, you can also improve tire life through active traction control in a hybrid tractor. As you would imagine, replacing tires on a wheel loader is a costly repair! And plans to continue development of electric machines. Tetsuo Ogawa recently sat down with Jim Shoemaker to learn more about what John Deere is doing and how they are using JMAG.

Electrification of Heavy equipment

—What was the trigger that caused you to start using JMAG

Mr. Shoemaker John Deere is moving into electrification and many of our new products now have electric drives. (See story on 644k Hybrid Tractor above, or add image/reference to newer model) We are also a company that is very much moving towards virtual prototyping so we are trying to remove as many vehicle prototype builds as we can. We would like to design it, simulate it, build the first mule (prototype), prove it and run it, all while reducing the number of prototypes. So we are simulating everything, mechanical, electrical, hydraulic, etc.

644k Hybrid Tractor
http://www.deere.com/wps/dcom/en_US/products/equipment/wheel_loaders/644k_hybrid/644k_hybrid.page

Jim Shoemaker
Technologies
Mgr Vehicle Electrification
Advanced Product Technology
John Deere

—What was the design process before JMAG

Mr. Shoemaker We typically purchased motors from suppliers based on specifications and performance data. We would build a test rig and run it on a dynamometer to verify that it met the specifications needed for the application including thermal and structural performance. So we always had to physically verify that the machines we purchased met our requirements.

—So you did not design your own machines

Mr. Shoemaker Mostly we tried to find available machines from suppliers. We did calculations based on geometry to try to understand machine performance but it was all Maxwell's equations used to estimate what we thought would meet our requirements.

—Electrification is important to John Deere, did you have to start creating custom designs to meet these internal requirements

Mr. Shoemaker That's true. Commercially available machines do not have the power or torque density we require in our applications. For example, think about how large a 500 Watt bench grinder motor might be at your home. We need a 500 Watt continuous duty motor to be about the size of your fist. Even a high performance servo motor is 2 or 3 times larger than motors on our products. John Deere requires much higher power and torque density from smaller machines. And the machines need to be sealed from water, dirt, fertilizer salts, and survive a lot of abuse. Our suppliers were not able to provide that with their catalog offerings.

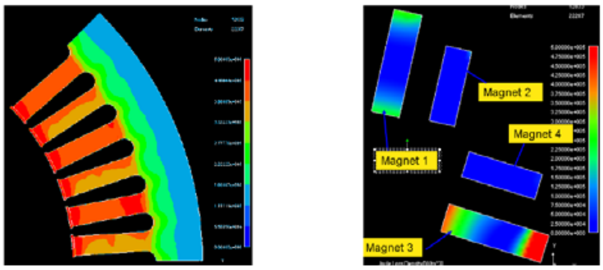
High fidelity model in virtual prototyping

—Do you use JMAG in conjunction with motor design programs like SPEED

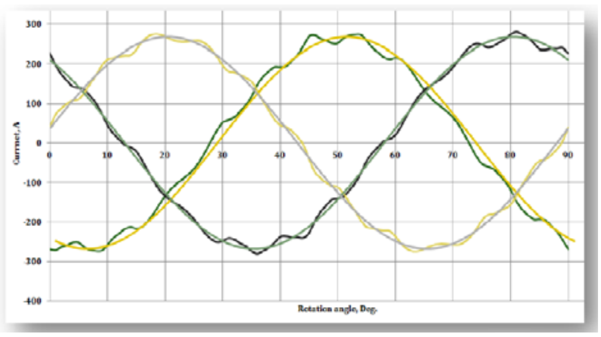
Mr. Shoemaker SPEED gives us a great performance prediction quickly. I can predict that the motor would put out 100 KW of power but SPEED is not a really good tool for digging deep into the losses. SPEED may predict 93-96% efficiency and the mechanical guys will ask what coolant flow rate is needed to cool the motor. That efficiency range represents nearly a factor of 2 in terms of having to reject 4KW or 7KW of heat. So the mechanical guys think my modeling is no better than a guess. They could throw darts in the dark and get better results in their opinion. Machine output is still about 100kW either way, so that's predicted pretty well, but how much heat I need to reject is where we are not sure. What is the exact efficiency, what is the torque ripple of that machine, how is it impacted by manufacturing tolerances, current or voltage tolerances, what can I expect out of the machine when these quantities are changed That's where we need to get a much better understanding.

—So the initial motivation for using FEA models was to better predict losses

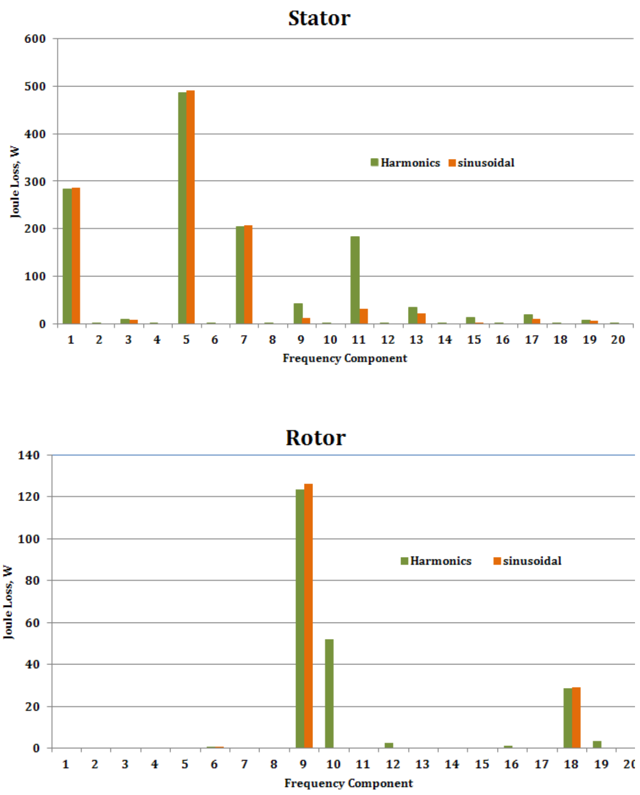
Mr. Shoemaker The first motivation was to get better performance understanding in terms of torque ripple, dynamic response, etc. The second was to get better understanding of the losses and controllability like adding one more turn into the machine gets you a little less current but do you have the voltage headroom to maintain dynamic control The answers we got from SPEED were not as accurate as we needed. We still use SPEED for initial calculation to get a basic idea for sizing the motor and performance. I would always go there first before I start doing an evaluation of something just to get a feel for it.



Core loss and magnet loss



Impact of current harmonics (PWM) on loss and efficiency prediction



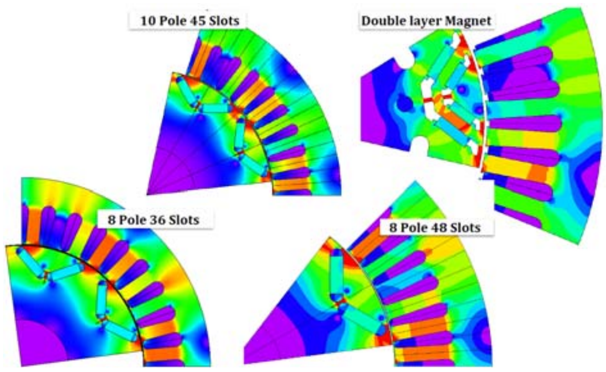
Frequency component of Joule loss

—How do you think JMAG compares in terms of speed and accuracy

Mr. Shoemaker I think it is as good as the other electromagnetic FEA packages, but I guess we don't re-evaluate simulation tools very often because of the big time investment in learning a tool. To me JMAG is missing a multi-physics connectivity. (Editor's Note, JMAG has recently added a Small Multi-Physics feature to do just that and we are planning to expand these capabilities) I want to be able to sit tight and run all analysis domains, like some of the other software packages do. I like the fact that we have the ear of JMAG. For example if I say I need a flux calculator, within a period of 3 months we have a flux calculator. I don't have that with other FEA suppliers. We have to accept what they send out. If I have trouble with my bus bar calculation, I can send it to JMAG and say "here JMAG, show me how this works" and you will figure it out.

—How many design cases could you evaluate before and after JMAG

Mr. Shoemaker Before simulation tools we would evaluate about 2 cases in 6 months. It is a lot of work to run machines on a dyno: providing adapter flange, shaft coupling, alignment, coolant, position sensor adaptation, configuring an inverter to properly operate an IPM machine and evaluate it through all its range, over temperature, saturation, short circuit, etc. Now I can evaluate about 50 in a week! We use SPEED to compare induction, IPM, and SR machines for an application and find a few worth investigating. We can compare single layers of magnets to dual layers of magnets, and multiple magnet angles and positions, and then select the cases that we want to do a deeper dive on.



Different rotor configuration study

—What do you mean by deeper dive?

Mr. Shoemaker First week I do a cursory evaluation of multiple cases and the next week I probably take 2 of them and take a deeper look using FEA and then I come up with what I think is about what I want. Then I work with the controls and application trying to see if this really performs as I need it to.

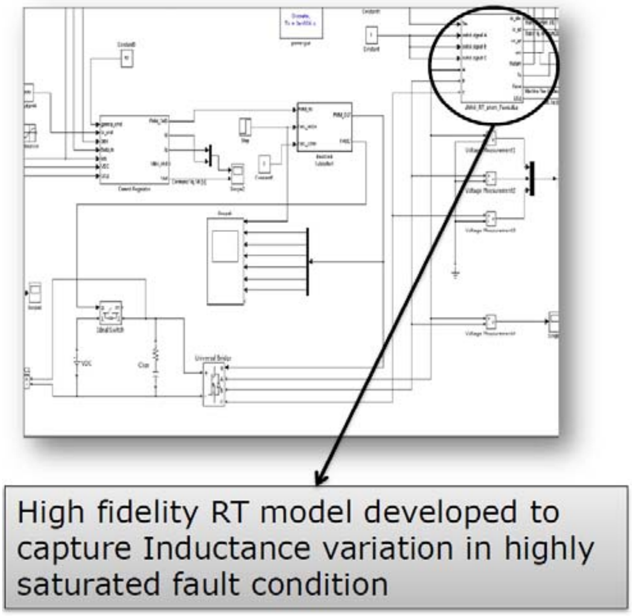
Advanced design for control systems

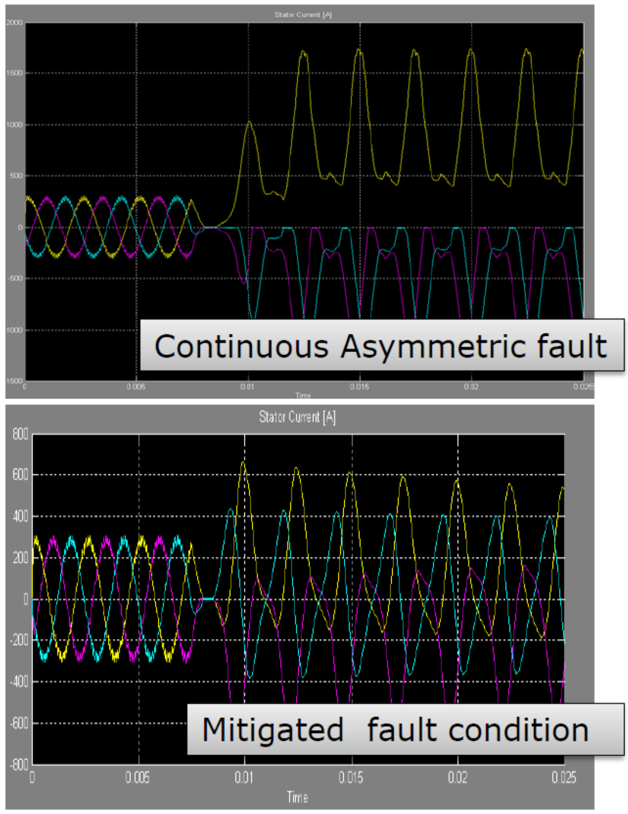
John Deere is also developing custom controllers for their machines. This is done by a separate group within John Deere called John Deere Electronic Solutions (JDES). Jim's group is responsible for the machine design and they have to communicate this design with the control team to allow them to simulate system performance. To do this, John Deere relies on JMAG-RT. JMAG RT allows Jim's team to create a high fidelity machine model and send the information as a block that can be used in their HIL system.

—What do you think is the biggest benefit of using JMAG RT

Mr. Shoemaker We are using it in a HIL system to characterize a controller for an IPM electric machine without putting the electric machine on the dynamometer. If we have accurate geometry and material data then we can accurately characterize the machine. We map the machine for maximum torque per amp, maximum efficiency, no load and full load conditions.

The other advantage with virtual tools is that you can run machines to the limits or past the limits without damaging hardware. You haven't burned up a motor or an inverter.





Integrated control simulation for fault mitigation

Advanced support and technical materials to accelerate the learning curve

—What do you think of JMAG's support

Mr. Shoemaker I think the support is superior to other FEA companies we have worked with. It's still never of course what I want. I want you to anticipate my needs, read my thoughts and whenever I ask you for something get it the next day. But of course it takes time to do things and the support really is quite good.

—What do you think about the online support materials such as the Application Catalog

Mr. Shoemaker I always like tools like that. The output from the User's Conference is also a good source. We go online and we read or download the files. It is always good to get other user experiences. Your tutorials online are very good too. They walk through most of the things everybody wants.

—Do these online tools help accelerate the learning curve

Mr. Shoemaker It does. Either for someone new to JMAG altogether or just someone who wants to run a new tool or feature. We can run the example and have one that works which lets us identify any issues and confirm whether an issue is related to the tool integration or the problem set up.

—From the point of the total cost, once the system is built using JMAG or HIL system, is it cost effective

Mr. Shoemaker Absolutely. Virtual prototyping is absolutely cost effective.

Expectation to advanced modeling with multi-physics

—In future, what do you expect with simulations using JMAG

Mr. Shoemaker The big push for us right now is thermal modeling. I can very accurately calculate the torque and speed of an electric machine. I can sort of accurately calculate my losses. It's not as good but it's ok. I don't have a clue how hot my motor will get. What power level can I run that motor to before I reach a 180o C hot spot in the center of the motor I don't have a good idea and I can be off by a factor of 2 even using JMAG and anything else because we just don't have a good tool that really predicts temperature that well. We are pretty good at predicting the performance, ok at losses but terrible at predicting thermal.

—For the future function point of view, what do you think JMAG should enhance

Mr. Shoemaker I am not so sure that I know that answer. Again bringing in more data to predict thermal performance better, just like you have imported the JFE steels, you brought that database in, that's not a feature in JMAG. It's just a database of steels but without it you can't get accurate results. The same thing is true for the thermal performance. You have tools that if you have a good estimate for all of the thermal impedances and capacitances you should be able to calculate performance, but we don't know all those things. We are not very good at getting from copper to slot liner to steel to water jacket, or knowing how well the coolant couples to the heated surfaces.

—So you mean the material properties for thermal should be included

Mr. Shoemaker Yes. That's our next threshold. We have some variable length motors and if we need more torque, we make the motor longer. We cool these motors by running oil into a jacket around the stator and also spray oil on the end turns. Once the motor gets about so long I can't thermally cool the windings at the center of the lamination stack. My question would be where do I hit the limit And if change the oil temperature or flow rate, what is the possible length now If I put more oil on the end turns does it help or is there so much differential across the steel it doesn't matter That's where our next frontier is. Getting this differential of how fast the heat flows through the copper to the ends and how well heat is removed. I guess it is a multi-physics problem but that's where I am at.

—It looks like not only the pure capability of the software but also the material, the solution, know-how and other components needs to be improved.

Mr. Shoemaker Yes. Even if the tool is good if the material information is not provided, the user would not know where the materials saturate or how they behave. All those things that come into using the tool are what we are lacking in thermal.

—So, in parallel to providing user tools, we also need to add "knowledge"

Mr. Shoemaker Yes. It is not a built-in knowledge-base for the tool now. It's just best guesses or at least an approximation that works. It is also a part of the request to the JMAG team.

This has been a theme we have heard from many of our users. We need to incorporate knowledge into JMAG's functionality. We have been working toward this, but additional feedback is always appreciated!

JOHN DEERE

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Product Report

JMAG Achieves High-Speed Calculation

JSOL continues daily efforts to develop new technologies for further acceleration of the JMAG solver.

This issue focuses on the performances of the JMAG high parallel solver and GPU solver boasting an exceptional level of calculation speed. This is a must-see for those who wish to calculate large-scale models quickly.

Introduction

Time allowed for electrical equipment design is becoming increasingly shorter every year. An important countermeasure to shorten design time is employment of Computer Aided Engineering (CAE). CAE related to the electromagnetic often uses Finite Element Analysis (FEA) that JMAG also employs, which leads to ultimate demands for eliminating FEA time to achieve shorter design periods.

JMAG also introduces a high-speed computation technology to reduce analysis time. This issue describes performances of the JMAG high parallel solver and GPU solver which have been newly implemented in JMAG-Designer Ver.13, and also explains precautions for using hardware to be selected.

JMAG High Parallel Solver

Up to now, JMAG users have used the SMP parallel solver that effectively utilizes multi-core CPU (Central Processing Unit) in a computer.

However, many users have been expecting reduced calculation times by a solver with high parallelism since the SMP solver supported just 8 parallels at maximum.To satisfy such demand, JSOL developed the JMAG High Parallel Solver (hereafter called MPP Solver) with high parallelism to realize a high-speed computation via a cluster system connected to multiple computers (hereafter called nodes) in a high-speed network. This solver enables using multiple cores in a CPU as well as multiple CPUs in the cluster, which achieves a higher degree of parallelism in analysis and increases calculation speed.

How to Use JMAG MPP Solver

Before using the solver, selection of appropriate hardware and MPI (Message Passing Interface) settings are required in addition to JMAG settings. This section describes the setting method in JMAG, key factors when selecting hardware and supported OS and MPI.

Settings in JMAG

When you click on the solver tag in the JMAG-Designer magnetic field analysis study property, the solver control will appear. Set the parallelism degree by selecting [Distributed Memory Multiprocessing (DMP)] for the parallel calculation type (Fig.1). Then, run an analysis.

Note: Execute an analysis from your job scheduler or command line for JMAG-Designer Ver.13. We provide a sample shell for those who run from the command line.
Starting an analysis from the JMAG Scheduler is also available in JMAG-Designer Ver.13.1 and later versions.

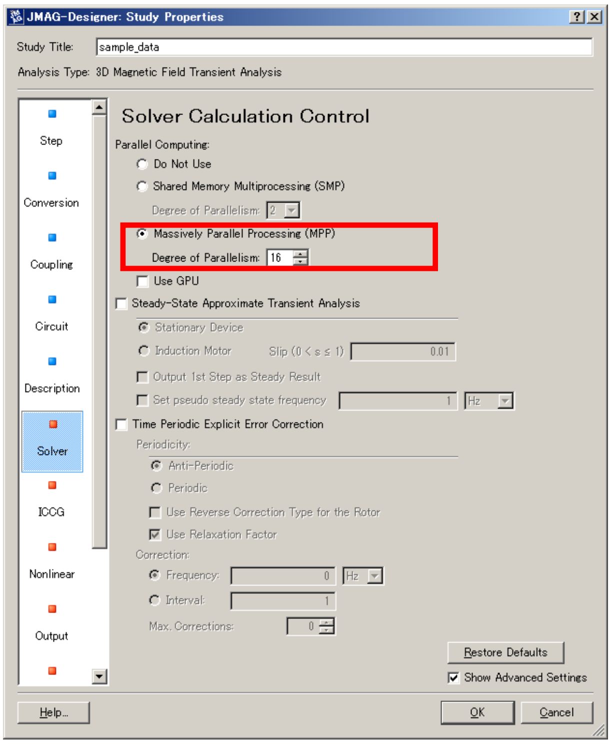


Fig. 1 MPP Solver Settings

License

To use this solver, a dedicated license (MPS license) is necessary instead of the conventional SMP parallel solver. When the degree of parallelism is less than or equal to 16, from 17 to 32 and 33 to 64, the solver uses 2, 3, and 4 licenses, respectively.When you are interested in greater parallelism, please contact us.

Key Factors for Selecting Hardware and Supported OS and MPI

The hardware you select is also vital to obtain high parallel performance with JMAG MPP solver. First, select a CPU with high memory bus performance for each node, such as Intel® Xeon® E5 Series or later versions. Filling all memory slots with physical memories also can enhance the hardware parallel performance (Fig. 2).

Supported OSs are shown below: It is possible to calculate using multiple cores in a node, but it is recommended you use multiple nodes for high-parallel calculation. In such cases, use Infiniband for a network between nodes.

Supported OSs are shown below:All are 64-bit OS.

・Windows

Microsoft Windows 7

Microsoft Windows HPC Server 2008 R2

・Linux

RedHat Enterprise Linux 5、 6

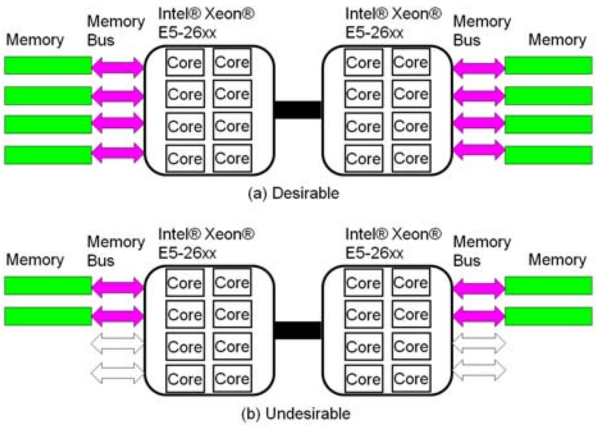


Fig 2. Examples of Hardware Structure

(Up: Good example of filling all memory slots
Down: Bad example of not filling all memory slots

MPP Solver Performance

Calculation speed evaluation

This section describes effects of enhanced speed performance using the JMAG MPP solver. The following table shows specifications of hardware used in the test (Table 1).

Table 1 Hardware Specifications

CPU	Intel® Xeon® E5-2670
Clock frequency(GHz)	2.6
Number of cores / processor	8
Number of processors / node	2
Memory (GB)	32
Number of nodes	16
Network	Infiniband (QDR)

Transient Response Analysis of Embedded Type PM Motors

We ran a transient response analysis for one period of electric angle for a large-scale 3D PM synchronous motor (approx. 2.06 million elements).As a result, only 2.5 hours and 1 hour and 45 min. were necessary for 32 and 64 parallels, respectively (Fig. 4).They are 13 times and 20 times faster than conventional non-parallel computing.

The following figure shows a cogging torque history as calculation results (Fig. 5).The finding shows the same results were obtained in high parallel computing as in non-parallel computing.

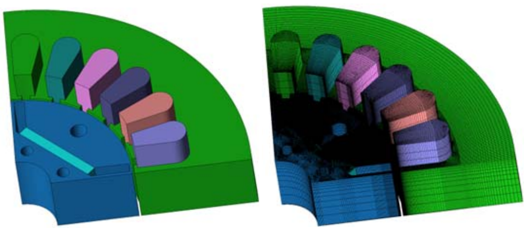


Fig. 3 Embedded Type PM Motor Model

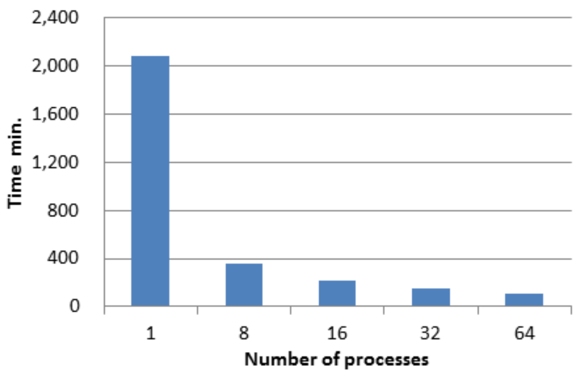


Fig. 4 Analysis Time (Embedded Type PM Motor)

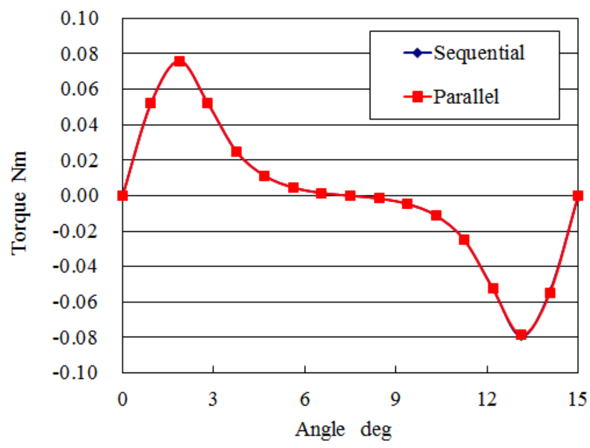


Fig 5 Cogging Torque

Bus Bar Frequency Response Analysis

A frequency response analysis was run for a large-scale 3D busbar (approx. 2.42 million elements) (Fig. 6).Non-parallel processing required approx. 60 minutes analysis time, but 32 and 64 threads needed approx. 6.4 min and 4.6 min, respectively (Fig. 7).The following figure shows current density distribution as a calculation result (Fig. 8).We obtained the same results both from high-parallel and non-parallel processing.

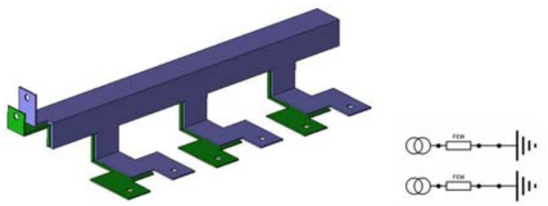


Fig. 6 Busbar Model

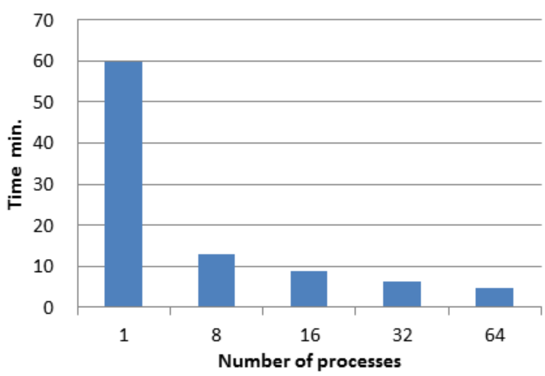


Fig. 7 Analysis Time (busbar)

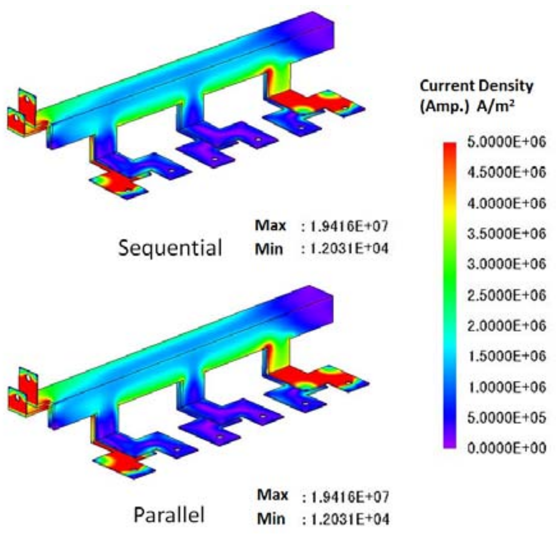


Fig. 8 Current Density Distribution

JMAG GPU Solver

In recent years, performance of GPU (Graphics Processing Units) has greatly improved. GPU overwhelmingly outnumbers CPU in terms of cores and effectiveness on parallel processing.

These days, GPU has been used as an arithmetic device for super computers as well as being used for conventional image processing because of its strength in parallel processing capability. GPU has attracted a lot of attention from the CAE field and GPGPU (General-purpose computing on graphics processing units) using GPU for general purposes, including math calculation, has been gaining popularity.We were early to spot GPGPU and have continued development since we first provided a GPU solver in 2012.

How to Use the JMAG GPU Solver

Settings in JMAG

JMAG GPU solver is easy to use. Clicking the [Solver] tag in [Study Properties] will display [Solver Control]. Then, only selecting the [Use GPU] checkbox enables you to use GPU.

Multi-GPU

JMAG GPU solver also supports the multiple GPUs and accelerates calculation speed by using them simultaneously. If your machine has multiple GPUs for math calculation, you can specify the number of GPUs used simultaneously. For instance, to use two GPUs, select [Shared Memory Multiprocessing (SMP)] by pressing the parallel computing radio button and set “2” for the degree of parallelism (Fig. 9). Either 2, 4 or 8 GPUs can be used simultaneously.

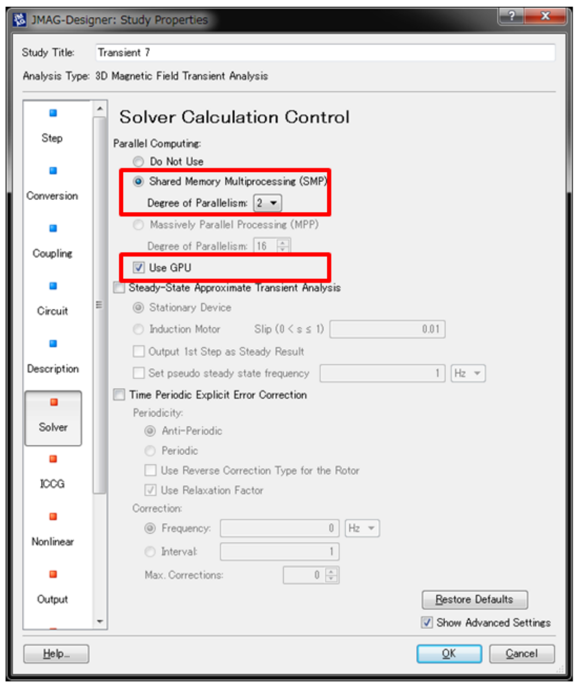


Fig. 9 Setting GPU Solver

License

A license for Parallel Accelerator 2 (hereafter called PA2) needs to be installed to use the GPU solver. The number of necessary licenses is the GPU plus one additional license. For example, using one GPU requires two PA2 licenses. Using two GPUs requires three PA2 licenses.

Hardware Environment

JMAG GPU solver supports only GPU for math calculation made by NVIDIA. The following GPUs are currently supported:

1. Tesla K40
2. Quadro K6000
3. Tesla K20
4. Quadro 6000
5. Tesla C2075
6. Tesla C2070
7. Tesla C2050

You are recommended to use the latest version of GPU as possible to better realize the effectiveness of the GPU solver.

Windows 64-bit is the only platform supported by JMAG GPU solver.

Static and transient response magnetic field analyses are also supported.

Recommended Calculation Target

GPU and CPU continuously communicate in the JMAG GPU solver. Therefore, when a 2D or 3D mesh model as a calculation target has several tens of thousands of elements, communication between the GPU-CPU can bottleneck as calculation times were not originally intended to be so long. When using the JMAG GPU solver, we highly recommend you use a mesh model as large as possible with more than 1 million elements.

JMAG GPU solver also uses special numerical solutions. Therefore, calculation of models including circuits may be poorly converged. Condition settings without using circuits such as using only current conditions are recommended.

GPU Solver Performance

Calculation speed evaluation

This section describes case studies evaluating JMAG GPU solver using NVIDIA's Tesla K40, the latest GPU for math calculation.

JMAG uses most of the calculation time for solution-finding, that is, processing iterative solutions of the linear equation obtained in the finite element method. Especially when using a large-scale mesh model with millions of elements, large proportion of the processing time is required for solution-finding. JMAG GPU solver employs a technology to accelerate such a processing time using GPU. This section shows a comparison of processing times required for solution-finding between the GPU solver and JMAG shared memory multiprocessing parallel solver. Hardware specifications of GPU and CPU used are shown below (Table 2).

Table 2 Hardware Specifications

Hardware	CPU Intel® Xeon® X5670	GPU NVIDIA® Tesla® K40
Clock frequency(GHz)	2.93	0.745
Number of cores	12 (2CPU)	2880 (1GPU)
Memory(GB)	24	12
Memory bandwidth(GB/s)	32	288

Static Magnetic Field Analysis of Embedded Type Permanent Magnet Motors

The following figure shows the total processing time used in solution-finding for each single analysis step when running a static magnetic field analysis in an embedded type PM motor model with 4 poles and 24 slots (Fig. 3, 1/8 partial model)(Fig. 10). This model has approx. 2 million elements. As a result, calculation completed in 14.4 min. when using a single GPU, while only 7.7 min. using two GPUs. The result shows that the use of one GPU board leads to approx. 30 times faster calculation time than a single CPU, and two GPUs shortens calculation time by approx. 1.9 times than using one GPU board.

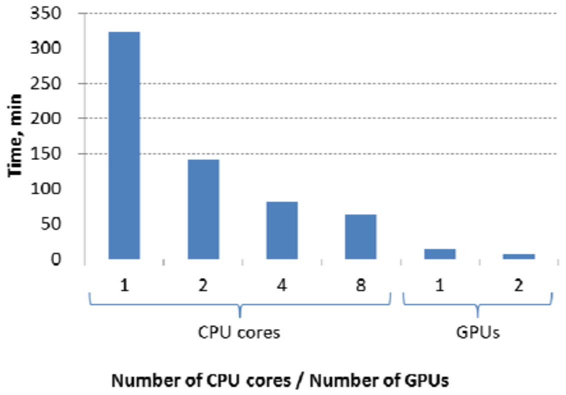


Fig. 10 Analysis Time (Embedded Type PM Motors)

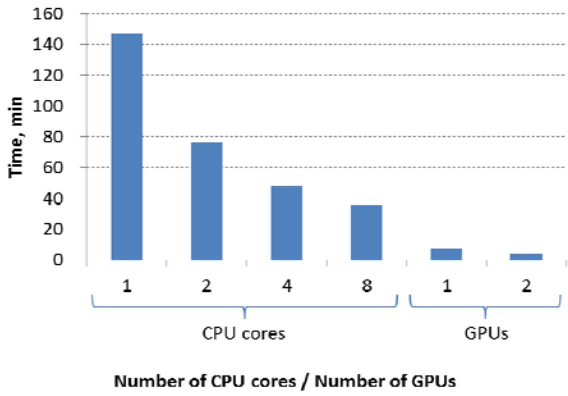


Fig. 12 Analysis Time (Linear Motors)

Linear Motor Static Magnetic Field Analysis

The following figure shows the total processing time used in solution-finding for each analysis step when running a static magnetic field analysis in a linear motor model (Fig. 11, 1/2 partial model) (Fig. 12).This model has approx. 7.5 million elements.As a result, it took 7.5 min. when using a single GPU, while only 4.2 min. using two GPUs. The result shows that using one GPU board leads to approx. 20 times faster calculation time than a single CPU core, and two GPU boards shortens calculation time by approx. 1.8 times than using one GPU board.

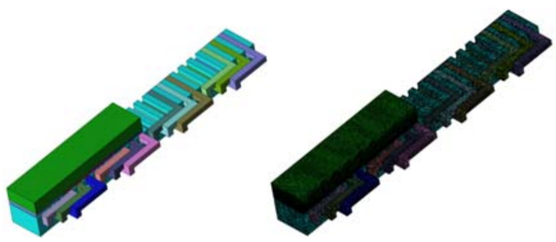


Fig. 11 Linear Motor Model

Induction Motor Transient Response Magnetic Field Analysis

Finally, this section shows the total processing time used in solution-finding for each single analysis step when running a static magnetic field analysis in an induction motor model with rotor skew (Fig. 13, 1/2 partial model) (Fig. 14).This model has approx. 9 million elements.The GPU memory for Tesla K40 has been boosted to 12 GB, which enables such a large-scale calculation with a single GPU board.With a single GPU board 71.3 min. was required, while taking 34.5 min. as two GPU boards were used.Considering a single CPU core needs 965.3 min. (approx.16.1 hours) of calculation time, GPU calculation is extremely fast.The result shows that using a single GPU board leads to approx. 14 times faster calculation time than a single CPU core, and two GPU boards shortens calculation time by approx. 2.0 times than using one GPU board.

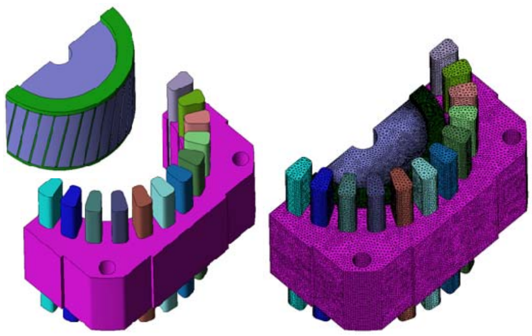


Fig. 13 Induction Motor Model with Rotor Skew

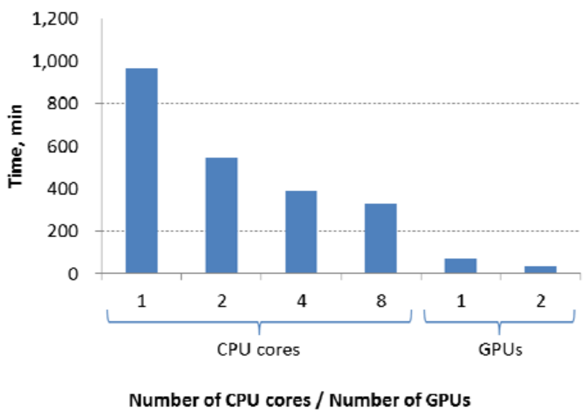


Fig. 14 Analysis Time (Induction Motors)

In closing

This issue described performances and how to use the JMAG MPP solver and GPU solver that reduce a great deal of calculation time.

In terms of the MPP solver, we continue to pursue a further improvement in the precision by shorting processing time in non-paralleled parts. GPU solver will support frequency response magnetic field analyses in the near future and cover wider range of analysis types.

Give the JMAG MPP solver a try and, at the same time, find out for yourself about the GPU solver performance.

(Masahiko Miwa, Kazuki Senba)

Product Report

PM Motor Design in JMAG-Express

Handy features are constantly added in our motor design tool, JMAG-Express. This article will use PM motors as an example and introduce case studies of motor design using the unique functions of JMAG-Express. We hope you will make use of JMAG-Express in improving efficiency in your motor design work.

What is JMAG-Express?

JMAG-Express is a motor design tool that covers examination from concept design, basic design to detailed design. It also packs 2 modes: quick mode that calculates basic properties in a second and a power mode that evaluates distribution of magnetic flux density or loss density, time series result of induction voltage and cogging torque. Flow of motor design that makes full use of JMAG-Express (Fig.1). At the concept design or the primary design stage, use quick mode for deciding on the rough layout of the motor, optimize the design parameters, then use power mode to complete the detailed design stage. This article will explain using JMAG-Express Public and JMAG-Express power mode. JMAG-Express Public is a free design tool that calculates the basic properties in a second like the quick mode in JMAG-Express.

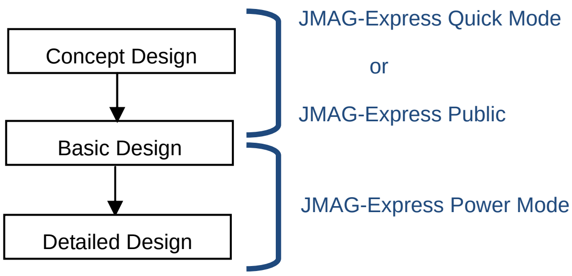


Fig.1 Design Flow using JMAG-Express

Motor Design using JMAG-Express Public

As an example of PM motors, I will introduce the method of motor design using JMAG-Express Public. Displays the desired specifications of the motor design in this article (Table 1). Displays the motor design flow using JMAG-Express Public (Fig.2).

Table 1 Desired specifications

Output	1.0（kW）
Efficiency	90（%） （Drive range that satisfies output 1.0kW）
Maximum Torque	2.5（Nm）
Supply Voltage	200（V）
Peak Current	5（Arms）
Maximum rotations	4000（RPM）

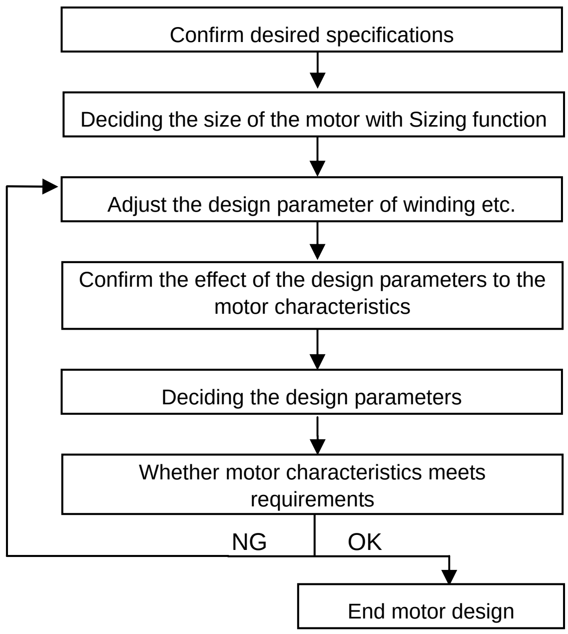


Fig.2 Design Flow using JMAG-Express

Instantaneously decides on the motor size from the desired specifications

To decide on the motor size from the desired specifications of the motor, knowledge and experience for motor design is required and it takes a lot of time. JMAG-Express Public has a sizing function and by simply setting the desired specifications of the desired rated power, the motor size will be instantaneously determined.

Let's use the sizing function of JMAG-Express Public to determine the motor size. First, select a geometry template. From over 200 templates, you can freely select and change the combination of rotors and stators (Fig.3). If the desired geometry is not listed, it is also possible to create a new template. Here, choose a SPM motor with a semi-cylindrical magnet. Choose the motor size from the desired rated power with the sizing function (Fig.4). Slot numbers and geometry dimension, as well as parameters of the materials are automatically adjusted.

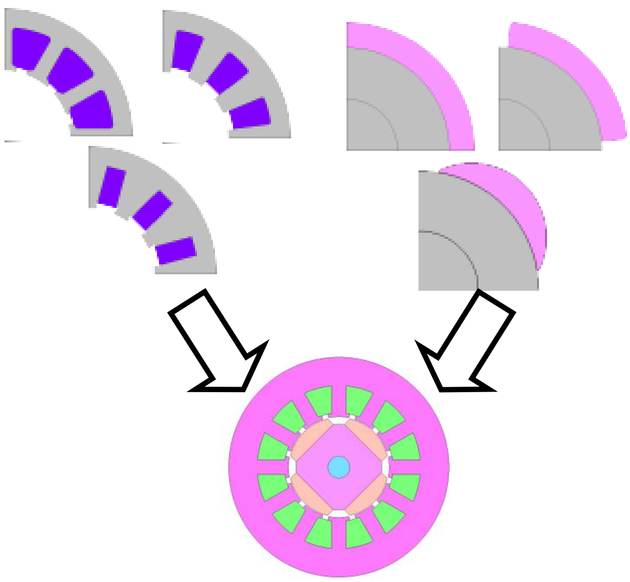


Fig.3 Selecting motor geometry type

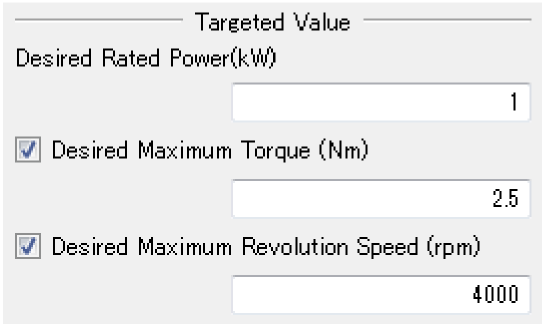


Fig.4 Setting example of the sizing function

Evaluation of winding

Since the motor size has been selected and the coil space has been determined, confirm the slot fill factor. The entire coil space cannot be used as the current region because some room is taken up by insulation. Regularly, you have to calculate coil space, lamination factor, and wire diameter on your own but in JMAG-Express Public, the lamination factor will be calculated automatically from the wire diameter and lamination factor information (Fig.5). It also automatically calculates the resistance, which changes depending on the winding type.

Here, change the wire to a round wire and confirm the motor characteristics by adjusting the slot fill factor by approximately 50% (Fig.6). With this, you can confirm that the targeted torque of 2.5Nm has not been reached at the 4000RPM mark.

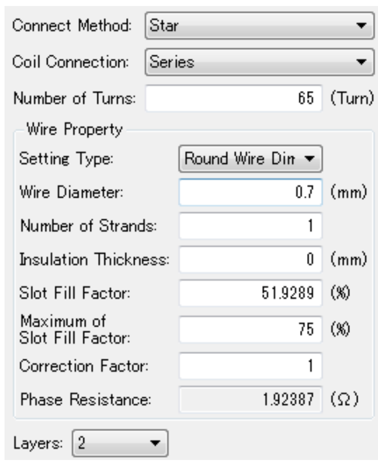


Fig.5 Winding Settings Screen

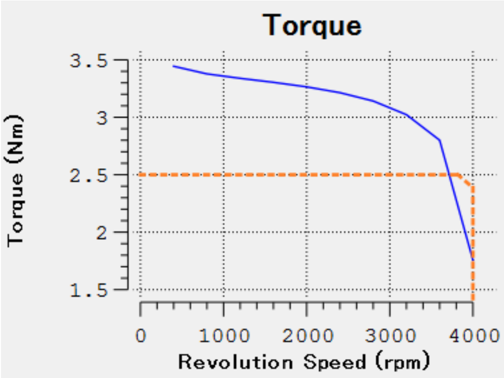


Fig.6 Torque Results (Primary Design)

Confirm whether the motor characteristics meets the requirements

As seen in Fig.6, the torque reaches to 3 Nm in the low rotation speed region so there is no problem, but at a rotation speed region of approximately 4000RPM, maximum torque of 2.5Nm is not satisfied. We would first like to fix this problem. It is assumed that the cause is the increase in the back electromotive voltage due to the increase in rotation speed. There is a possibility that the magnet is too strong, so I will change the geometry of the magnet to reduce magnetic flux. This time we will try reducing the magnet width (Fig.7). Properties of all rotation speed regions can be confirmed instantaneously so I will set an appropriate value while changing the magnet width. This time, we will consider the change in magnet width as revised proposal 1 and compare with the primary design proposal. JMAG-Express displays multiple design proposals in one graph, and allows easy comparisons (Fig.8, 9). We have secured torque of over 2.5Nm even with 4000RPM.

Next, confirm the current density of the coil. When a coil is in a natural convection cooling state, there is a need to keep the current density below $1.0\text{x}10^7$ A/m2. In JMAG-Express Public, on top of torque or output, the current density of the coil or magnetic flux density of each part can also be confirmed (Fig.10). You can see that the current density of the coil is a little high, as it $1.4\text{x}10^7$ A/m2. I would like to increase the slot area to decrease the electric current density by changing to a wire with large diameter. JMAG-Express Public allows you to freely change the geometry dimension while fixing the gap length, which largely affects the torque. Here, we will increase the slot area by shrinking the back yoke, which relatively has leeway in magnetic flux density of 0.66T while retaining the gap length (Fig.11). As the slot area has gotten bigger, although the number of turns has stayed the same, the wire diameter has gotten bigger and the electric current density of the wire has decreased (Fig.12). We were able to achieve output of 1.0kW as well as a maximum torque of 2.5Nm.

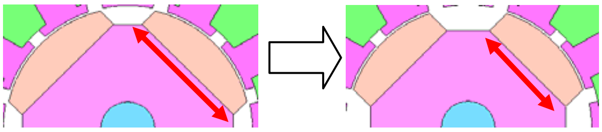


Fig.7 Change in magnet width (revised proposal 1)

	Graph	Width of Magnet	Ld	Lq	Self Inductance	Mutual Inductance	Kt	Ke
1	☑ ■	21.4	6.556e-03	7.616e-03	4.724e-03	-2.362e-03	5.127e-01	5.127e-01
2	☑ ■	18	6.451e-03	6.947e-03	4.466e-03	-2.233e-03	4.435e-01	4.435e-01

Fig.8 Startup window of the displayed design proposal

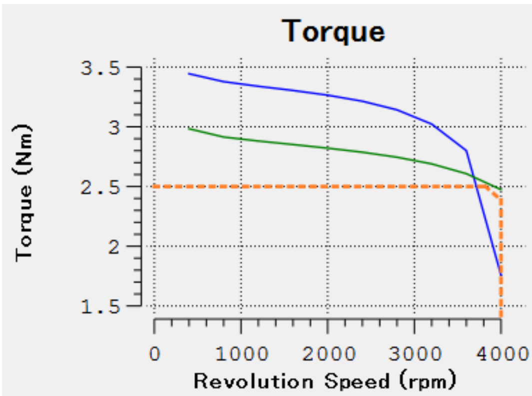


Fig.9 Torque comparisons
(primary design proposal and revised proposal 1)

Average Teeth Flux Density	Average Back Yoke Flux Density
1.456e+00	6.605e-01

Average Gap Flux Density	Wire Current Density
5.850e-01	1.483e+07

Fig.10 Calculation result of revised proposal 1

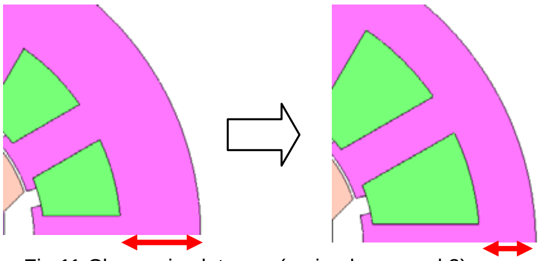


Fig.11 Change in slot area (revised proposal 2)

Average Teeth Flux Density	Average Back Yoke Flux Density
1.462e+00	9.743e-01

Average Gap Flux Density	Wire Current Density
5.799e-01	7.267e+06

Fig.12 Calculation result of revised proposal 2

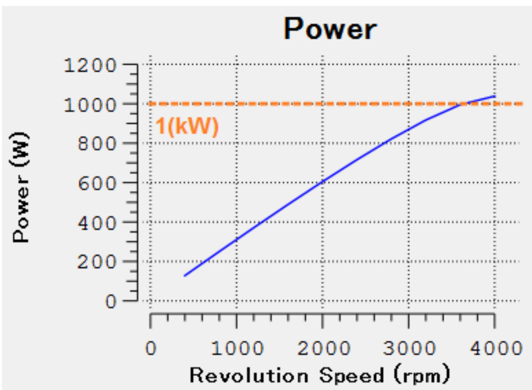


Fig.10 Characteristics result of revised proposal 2

Higher precision with JMAG-Express power mode

In receiving examination results in JMAG-Express Public, we will proceed with specification evaluation in JMAG-Express power mode. Displays motor design flow using JMAG-Express power mode (Fig.14).

In JMAG-Express Public, we evaluated using average of the magnetic flux density and the torque but in JMAG-Express power mode, we can evaluate time series results or torque, loss density distribution or magnetic flux density (Fig.15). With magnetic flux density distribution or information of the flux line, confirmation of magnetic saturation, we can confirm that the magnetic steel is effectively used. Also, from the torque waveform, we can consider change in geometry to decrease the toque ripple (cogging torque), which is the cause of noise. As you can see, we will be able to effectively design a magnetic circuit for the motor using JMAG-Express power mode.

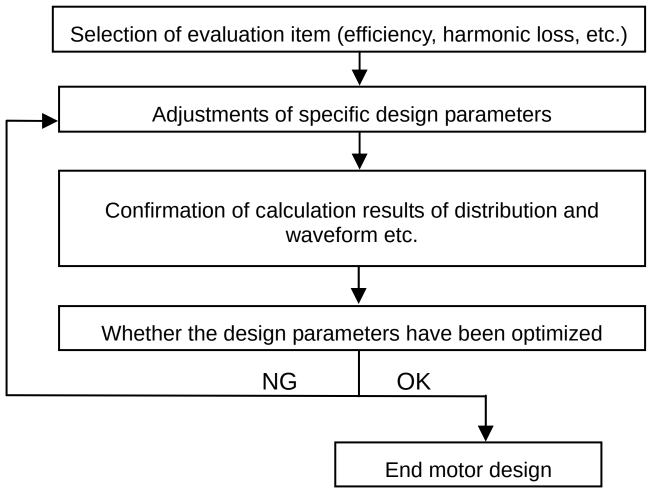


Fig.14 Design flow using JMAG-Express power mode

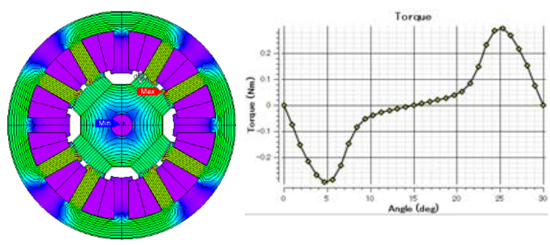


Fig.15 Result examples obtained in JMAG-Express power mode (left: magnetic flux density distribution and flux line, right: cogging torque)

Motor design making use of the efficiency map

Regularly, obtaining an efficiency map takes time but in JMAG-Express, it is easy. Here, use the power mode in confirming the efficiency map of the entire drive region. When evaluating efficiency maps, select [Basic Properties] in evaluation items, and put a check in "Efficiency" for the calculation target (Fig.16). The rest is to simply run an analysis, then an efficiency map obtained from detailed calculation using the electromagnetic field FEA will be displayed (Fig.17). We were able to confirm that with a revolution speed of 40000RPM that fulfills output 1kW, we satisfy 90% of efficiency.

In addition to the efficiency map, we were also able to confirm copper loss and iron loss maps. We are able to confirm that in a heavy load region, copper loss increases and in a high rotation region, copper loss increases; we are able to tell the cause in the efficiency map. By using power mode, you can find the ideal design parameters.

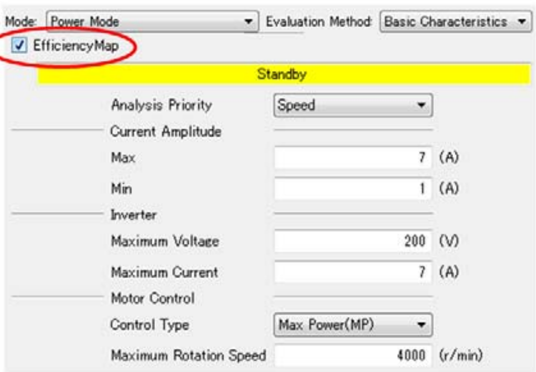


Fig.16 Setting of power mode in JMAG-Express

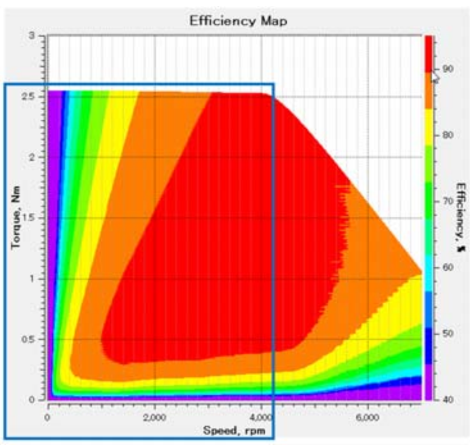


Fig.17 Efficiency map

Start motor design with JMAG-Express Public

Through using JMAG-Express, I believe that I made it clear that a consideration from concept design of a motor to a detailed design is possible. On the other hand, I hope you were able to see that JMAG-Express Public alone allows you to consider motor design. To experience JMAG-Express, I recommend starting motor design from our trial version of JMAG-Express Public.

JMAG-Express Public is easy to obtain, so please grab a copy of the software and license with the method below.

1. Download

   Access the JMAG-Express Public website and download JMAG-Express Public.

2. Obtaining a license key

   Register a license key from the JMAG-Express Public homepage.

3. Install and set the license key

   Install JMAG-Express Public and input the license key.

JMAG-Express Public Website URL

http://www.jmag-international.com/express/index.html

Lastly,

I hope you use JMAG-Express for motor design. JMAG-Express Public is free and is a motor design tool that can be used by anybody. The next version of JMAG-Express Public comes equipped with a parametric analysis function. Please try out this feature as well.

Please also try JMAG-Express power mode. JMAG-Express power mode will require an onerous license.

(Tetsuya Hattori)

Motor Design Course

Issue 3
How to Perform Detailed Motor Design

This series features descriptions of our thoughts about motor design, targets beginning motor designers and provides information about design themes for those seeking to acquire basic knowledge about the subject. In the previous issue we discussed initial designs, arranging concept design plans as a starting point for detailed designs. In this edition, the third and last entry in the series, we will look at detailed designing for final designs.

Trade-offs are a key factor when it comes to detailed designs and they also happen to be areas in which JMAG-Designer and JMAG-Express excel. By describing case studies developed through trial and error while using JMAG-Designer or JMAG-Express we plan to provide hints that will help you move ahead with detailed design of motors.

Detailed Design of Motors

After completing a concept design and confirming that it satisfies requirements it's time to move onto detailed design of the motor. This is the real thing for motor designers. I've been using the term "detailed design," but I could put it another way and say it's a "final design." It's everything, right down to part costs and production. Without that much knowledge it's not possible to make an actual machine. Even if a design doesn't need to include a dimensional drawing, designers' thoughts should be directed to a point just short of that. Motor designers have to overcome the doubts borne by designers or motor technicians who will take the motor parts and use them to assemble the actual machines. Motor designers are the only people capable of overcoming those doubts. Designers will be asked things like "We've got to make this dimension 0.5 mm, but I can I make it 0.6 mm?" and respond, based on principle, by saying: "No, we'll make it 0.5 mm as it's supposed to be." "And here are the reasons why it has to be that way," before launching into an explanation for the reasons why the dimensions have to be the way they were designed. This is not something that applies only to motor design. We take this approach when it comes to developing software and a ramen noodle restaurant operator is doing the same thing when they propose adding a new item to their menu. The pain involved in the final stages of production is the most difficult to deal with.

My apologies for taking so long to go through the introduction and get to the point, but the key factors in detailed design are:

- Shaving away waste
- Scrutinize trade-offs and balance them with high-dimensionality
- Enhance quality
- Ensure a sufficient degree of reliability

Strictly speaking, none of these are standalone items, but as we move ahead while examining detailed design with these themes in mind, it all boils down to coming close to getting a decent product by keeping these matters in mind.

For this third part of the series I would like to move ahead with discussion of detailed design of motors while explaining typical examples of case studies using JMAG-Express Public or JMAG-Designer. Here are the conceptual design items written about in the first two editions (Table 1).

Table 1 Specifications Decided in the Concept Design

Parameters	Specifications
Format	Inner Rotor SPM
Number of Poles	4
Number of Slots	12
Outer Stator Diameter	φ80 mm
Rotor Radius	φ40 mm
Stack length	51 mm
Coil Turns	60 turns/pole
Coil Resistance	0.77 Ω/phase
Coil Wire Diameter	φ1.0 mm
Peak Current	7 Apeak
Core	50A400
Magnet	Neodymium Sintered
Weight	2(kg)
Maximum Torque	2.5 N·m
Maximum Number of Rotations	4000 rpm
Output	1 kW

Shaving Away Waste

First, let's get rid of any waste. An example of an easy to understand waste is a magnetic path with extremely low levels of magnetic flux density. Getting rid of these areas lightens the work. Alternatively, sorting coil circuits may reduce copper loss. However, in reality in most cases there is rarely ever a great deal of unconditional waste and that means there are often trade-off problems results from cutting into breathing space.

Magnetic paths inside the rotor can be given as an example of waste that's easily overlooked. The shaft needs to be checked and verified, so there's value in giving it an examination because you don't want to shave off more than necessary due to the magnetic path. Above all make sure you have the minimal space needed for the magnetic path (Fig. 1).

In our concept design the shaft diameter was 16 mm and we allowed another ±8 mm scope to this. Enlarging the shaft diameter means narrowing the rotor magnetic path.

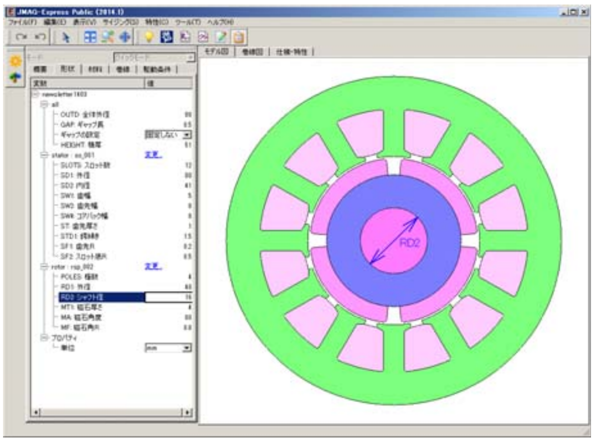


Fig. 1 Examining the Shaft Diameter

Look at the difference in shaft diameter affects the correlation between the rotor weight and torque constant and between the speed-torque characteristics (Figs. 2 and 3). As a result of allowing for the shaft diameter (hole diameter), even though we are narrower than the 16 mm of the concept design, it didn't enhance the torque constant. This is because we were showed that the magnetic resistance within the magnet had an initial value that was low enough that boosting the magnetic paths would only increase weight and create waste. Alternatively, raising the number to 20 mm had almost no effect and widening up to 24 mm did not leave enough room for the magnetic path within the magnet, which dropped the torque constant.

We now know that if the shaft hole diameter can be widened from 16 mm to 20 mm without adverse effect. Incidentally, the rotor core weighs 235 g, but we can lighten this by 40g to make it 191 g. In a motor with an overall weight of about 2kg, this may seem an insignificant contribution, but waste is waste, so we'll change it to 20 mm.

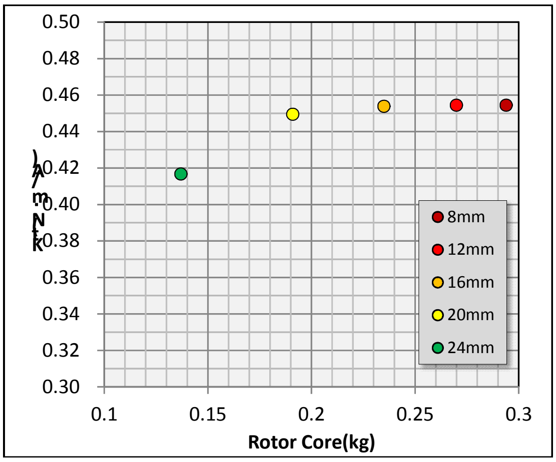


Fig. 2 How Shaft Diameter Differences
affect the Rotor Weight-Torque Constant Relationship

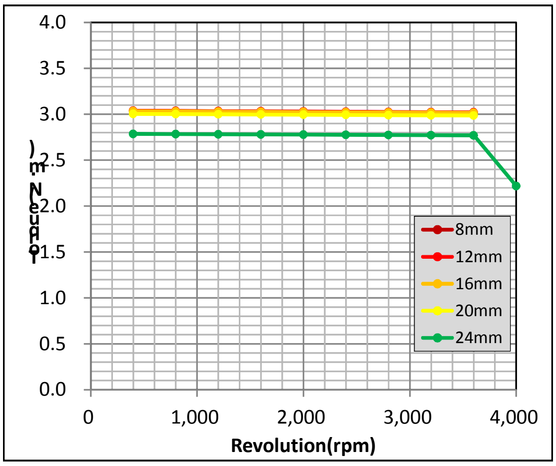


Fig. 3 How Shaft Diameter Differences
affect Speed-Torque Characteristics

Scrutinizing Trade-offs

The most challenging aspect of design comes in the trade-offs. Something working out may mean something else no longer working out, so fixing up clearly contradictory design parameters is the designer's job.

Here, we'll examine the yoke width in the stator core. If you fix the outer diameter and stack length, there'll be almost no impact on the overall outer layer or weight. One of the items a motor designer must examine is being adept at achieving balance in the motor interior. Thickening the core-back reduces the risk of magnetic saturation, but it also applies pressure on the coil winding space and increases the resistance and copper loss. Making the core-back has the opposite effects. To appropriately control copper loss, study dimensions to get them right and avoid magnetic saturation, which is a prime example of a trade-off, arrangement and compromise.

We changed the initial core rear value of 8 mm by ±2 and examined it (Fig. 4). At the same time we changed the wire diameter to maintain the coil at 60 turns and lamination factor at 50.4%, synchronizing this with only the resistance. Show Parameters (Table 2).

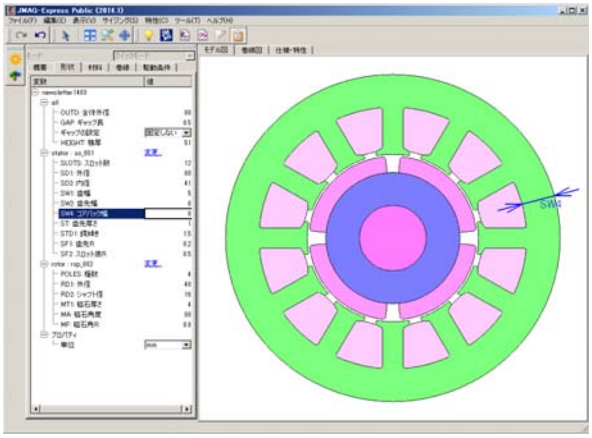


Fig. 4 Examining the Core-Back

Table 2 Wire Diameter and Resistance in the Core-Back Width

Core-Back Width	Wire diameter	Resistance
6 mm	φ1.12 mm	0.457 Ω
7 mm	φ1.06 mm)	0.504 Ω
8 mm*	φ1.00 mm	0.559 Ω
9 mm	φ0.94 mm	0.625 Ω
10 mm	φ0.87 mm	0.720 Ω

Let's check up on what happens to the relationship between resistance and the torque constant when you change the core-back width. Increasing the concept design's 8 mm does not change the torque constant, so we know that we still have room to move in regard to the magnetic path if we use the initial values (Fig. 5). And we also learn that resistance decreases the slot area, which increases linearity and shows that widening the core-back from its 8 mm has not benefit. But if we narrow this, the torque constant drops the more we reduce the width and it starts to show an effect on the magnetic path. You can confirm also that when it comes to resistance, linearity decreases.

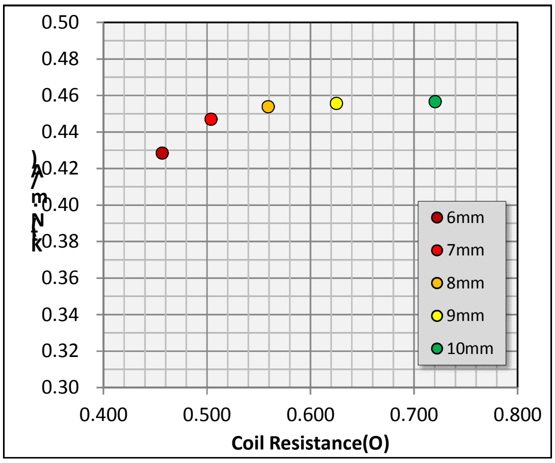


Fig. 5 How Core-Back Width affects the Resistance-Torque Constant Relationship

Checking out the speed-torque curve depending on differences in the core-back width shows few characteristics at 7 mm to 10 mm, but at 6 mm, you can confirm signs of the maximum torque dropping (Fig. 6).

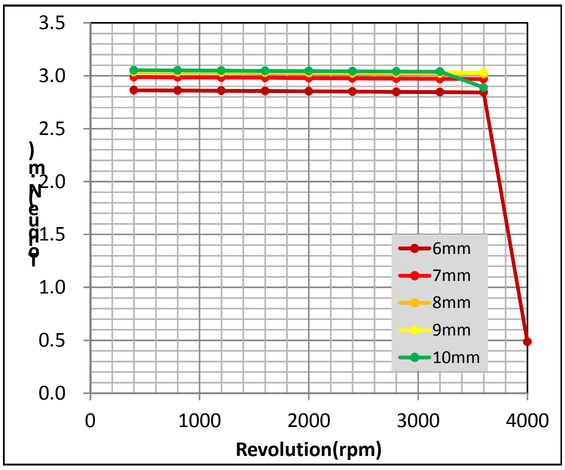


Fig. 6 Speed-Torque Characteristics Depending on Differences in the Core-Back Width

Now looking at the speed-efficiency characteristics reveals that efficiency increases in conjunction with the decreased resistance that results from narrowing the core-back, but lowering it beneath 7 mm shows almost no difference (Fig. 7). Integrating all these factors leads to changing the core-back width to 7 mm.

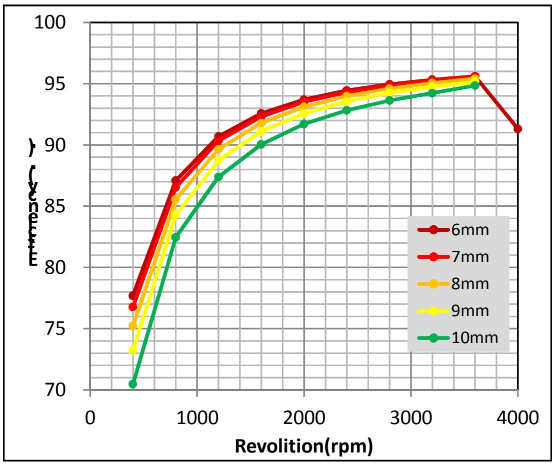


Fig. 7 Speed-Torque Characteristics Depending on Differences in the Core-Back Width

Next, let's examine teeth width. Positioning on the magnetic path is the same as the core-back width, which enables expanding the coil area through narrowing the teeth width, which raises expectations of being able to decrease resistance, but also heightens the risk of magnetic saturation. And that means the focus of our examination should be achieving a balance between resistance and magnetic saturation. In the concept design, the teeth width was 5 mm, so we will add another ±2 mm to its scope (Fig. 8).

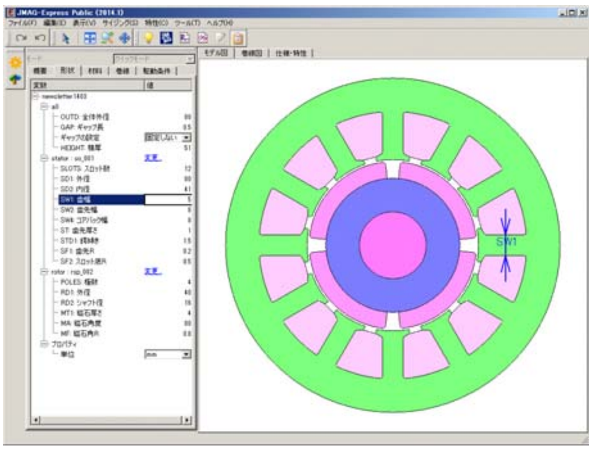


Fig. 8 Examining Teeth Width

Taking a look at the resistance-torque constant relationship while changing teeth width makes it easy to understand that changing the teeth width had a trade-off relationship with resistance and magnetic resistance (Fig. 9). Narrowing the teeth width from 4 mm to 3 mm drastically boosts magnetic saturation and the torque constant is lowered. On the other hand, there is no change in the torque constant from 6 mm to 7 mm, which looks space to maneuver on the magnetic path. Checking the teeth shows that even with average magnetic flux density it still achieves 1.8 T at 4 mm and that the ordinary saturated magnetic flux density of silicon steel sheets is approaching 2.0 T (Table 3).

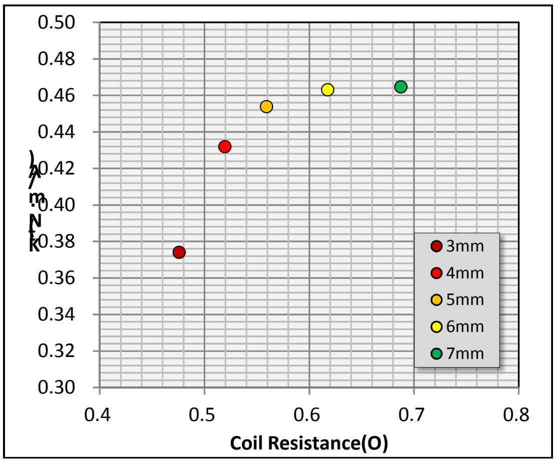


Fig. 9 Resistance and Torque Constant due to Teeth Width Differences

Table 3 Teeth Width and Average Magnetic Flux Density (Teeth)

Teeth width	Resistance	Magnetic flux density
3 mm	0.476 Ω	1.978 T
4 mm	0.520 Ω	1.799 T
5 mm*	0.559 Ω	1.561 T
6 mm	0.618 Ω	1.353 T
7 mm	0.687 Ω	1.171 T

Looking at the speed-torque characteristics after changing the teeth width we learn that the torque constant hasn't changed after 5 mm or more, so there is almost no variation in the maximum torque (Fig. 10). But we also learn that narrowing by 4 mm or 3 mm will reduce the maximum torque.

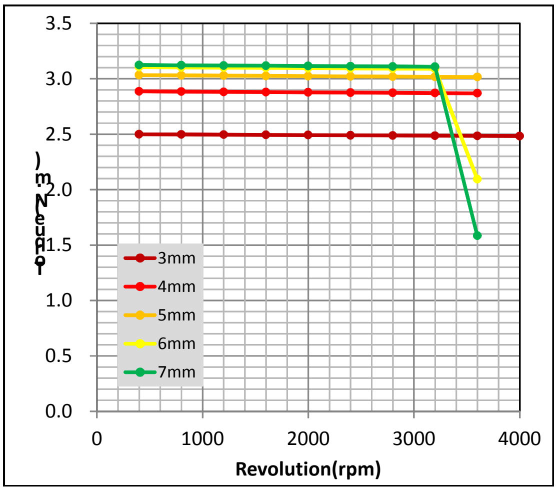


Fig. 10 How Differences in Core-Back Width affect Speed-Torque Characteristics

As reducing the torque constant is the equivalent of lowering the induced voltage constant, gaining a grasp of the output properties at high rotation would seem to have some appeal from a design viewpoint, but if you're looking for high rotation, a better and more correct approach to achieve this would be to reduce the number of coil turns and magnet weight. With the benefit of some magnetic flux, there's no benefit in spoiling it by making the teeth more detailed.

Now, let's check on the thickness of the magnet. It goes without saying that you need to carefully scrutinize how much you use NaFeB magnets in particular, as their material cost is extremely high compared to other motor parts.

Thickening the magnets increases magnetomotive force within the magnet itself. However, as the magnet's relative permeability is almost 1.0, when it comes to the motor's magnetic path, thickening the magnet also expands the air gap by the same amount of thickness added, which ups the magnetic resistance across the entire magnetic path and there is not an increase in the amount of magnetic flux equivalent to the increases thickness. The conceptual design was 4 mm, but let's look at it with a scope of an additional ±2 mm (Fig. 11).

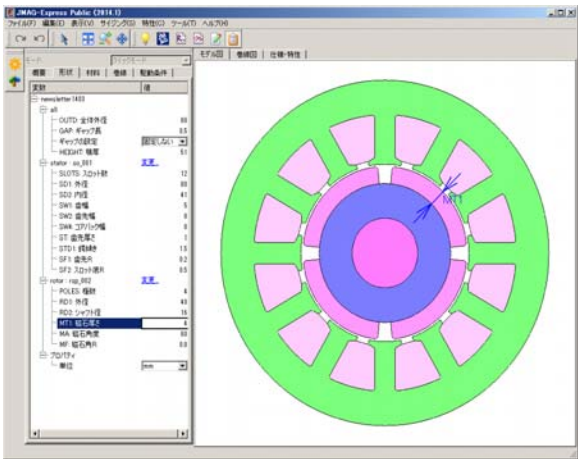


Fig. 11 Examining Magnetic Thickness

Take a look at the relationship between magnet thickness and magnet weight (Fig. 12). Making the magnet thicker than the concept design doesn't increase the torque constant. As stated earlier, this boosts magnetomotive force and magnetic resistance. On the other hand, making the magnet thinner greatly reduced the torque constant. A motor's magnetic path contains a rotor, stator and air gap, as well as the magnet. Making the magnet thinner makes the unchanging air gap relative thickness relatively more effective, so you can conform how making a magnet thinner greatly affects the torque constant. A check of the speed-torque characteristics shows that a change in the torque constant will leave output characteristics expressed in the same manner (Fig. 13).

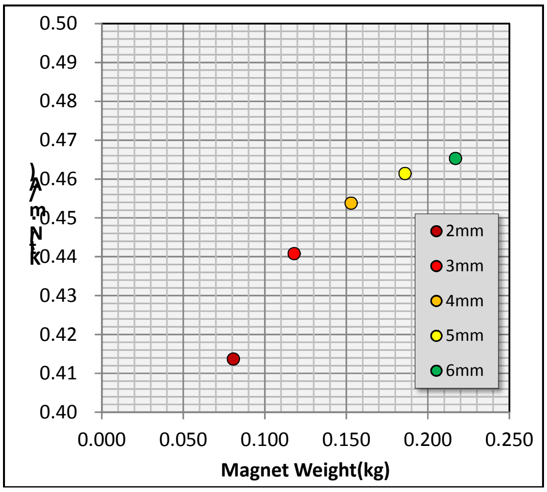


Fig. 12 Magnet Weight and Torque Constant Depending on Magnet Thickness

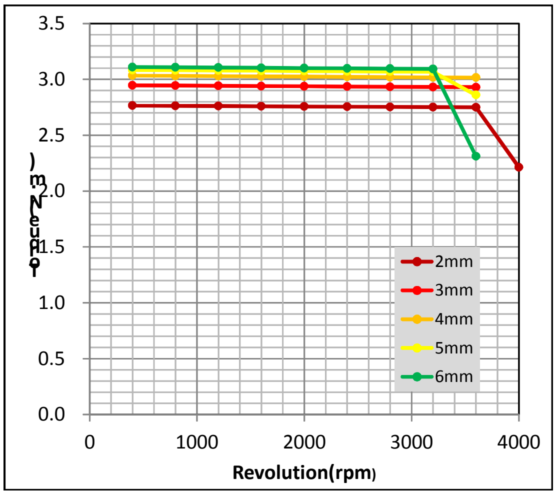


Fig. 13 Effect of Different Magnet Thicknesses on Speed-Torque Characteristics

After a check of the relationship between magnet thickness and speed-torque characteristics, we can confirm that it's probably best to thin the concept design's 4 mm down to 3 mm. But to decide on the actual thickness to use, you must allow for factors like irreversible demagnetization and thermal demagnetization. Calculation accuracy is crucial for this kind of analysis, so using a highly precise software like JMAG-Designer would be a wise choice.

With conventional motor design there are also sorts of other trade-offs that need to be considered, but writing all of them would require an entire book in itself, so I'll leave talk about trade-offs here and move onto our next theme, which is enhancing quality.

Enhancing Quality

For the purposes of this exercise, we'll regard quality as being the reduction of torque variations, like cogging torque, and the causes of vibration. Cutting both of these will lead toward improved quality.

For example, run a sensitive solver like JMAG-Designer for geometries like cogging torque. Here, we can confirm how cogging torque will change according to the angle parameters used for the magnetic pole's arc. JMAG-Designer analysis windows are packed with settings parameters or results analysis even though it is intended for general purpose use and these capabilities enable running highly accurate analyses (Fig. 14).

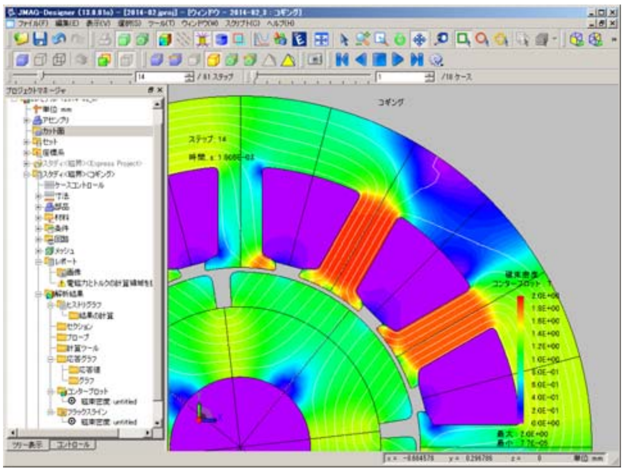


Fig. 14 Examining Magnet Angle

Analyze the obtained cogging torque waveform (Fig. 15). In the concept design the angle at the magnetic pole was 80 deg with intervals at 10 deg. The cogging torque at this time was ±0.65 N・m. Narrowing the magnet angle broadens the intervals and drops the cogging torque, enabling confirmation that narrowing to 68 deg will lower it to ±0.15 N･m. But narrowing it any more than this will, conversely, increase the torque variations.

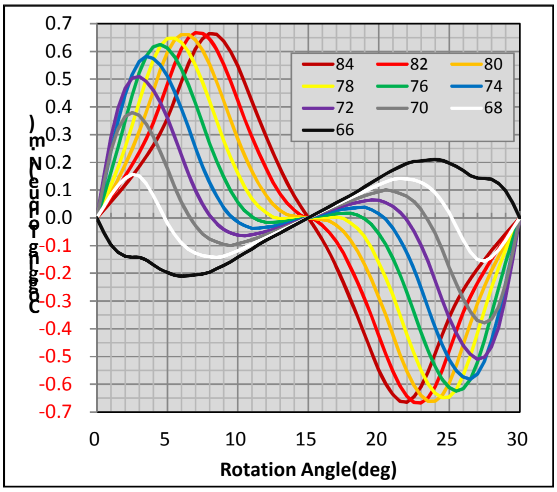


Fig. 15 Cogging Torque Waveform

Narrowing the magnet angle to cut the cogging torque will naturally also reduce magnetic flux, which connects to a lower torque constant. Obtained the induced voltage waveform (Fig. 16) at this time from JMAG-Designer. The number of rotations is 600 rpm.

A feature will be that amplitude in the induced voltage waveform will be in the vicinity of 14 V and there will be no great difference. With this waveform you can see that it's biggest near the square wave where the magnetic arc angle is largest and the higher components increase as the angle gets smaller. When the cogging torque reaches its smallest figure of 68 deg, the maximum has increased to 15.5 V, while at 60 deg it lowers to 12 V. Drastic changes in induced voltage such as those seen here makes it hard to maintain sinusoidal waves in the current and becomes a cause of iron loss, so it's a factor requiring plenty of caution.

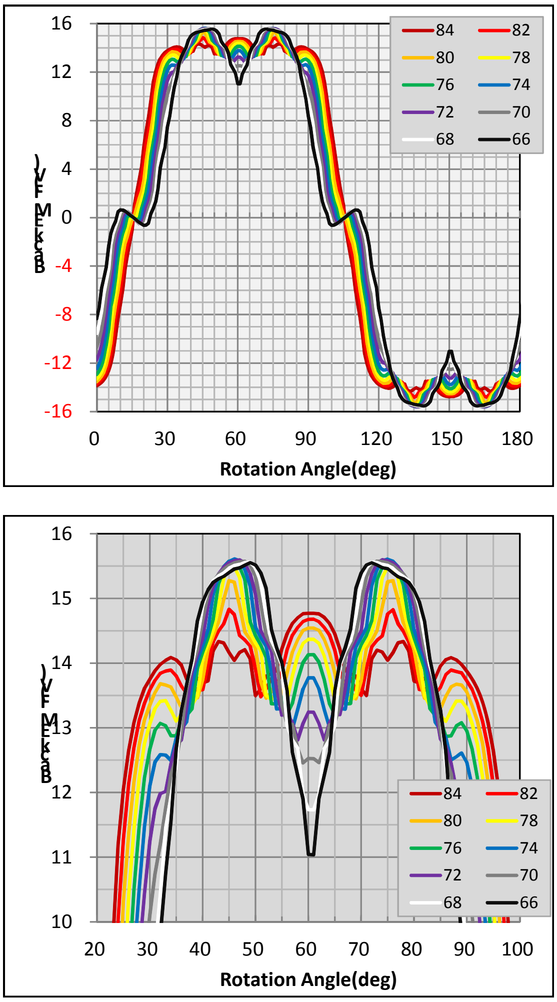


Fig. 16 Induced Voltage Waveforms Above: One period, Below: Peak Vicinity

Now let's analyze the results of FFT processing of the induced voltage waveform (Fig. 17). Changing the magnet angle from 84 deg to 64 deg lowers gap flux linkage to 78% in a simple conversion. Coinciding with the narrowing of the voltage amplitude in the waveform of 20 Hz is gradual reduction that will lower voltage from 17.5 to 15.8 V, but 91% will be retained. However, the 60 Hz component, which corresponds to the slot harmonics, will drop from 4.6 V to 0.6 V, a significant decrease of 14%. However, after a temporary downturn through five rotations of the 100 Hz component, it showed signs of moving upward rapidly and ultimately doubled from 1.8 V to 3.3 V. In this manner, the motor has qualities unable to be read in the waveform alone, which means that ultimately the only item capable of providing a decision is a highly accurate tool.

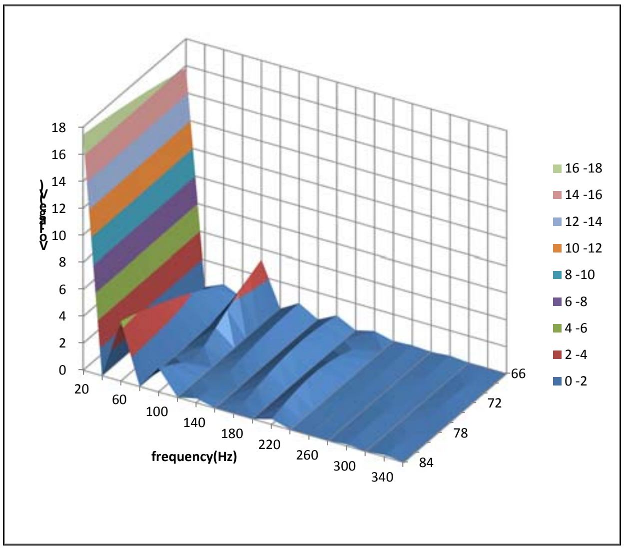


Fig. 17 Induced Voltage Vector Comparison for Each Magnet Angle

Is this Reliable Enough?

You've ensured the performance, raised the quality and now all that's left is reliability. We're talking about electric machinery, so it's only natural that it has output, but to be useful in the real world, it has to have a stable and reliable performance in a variety of environments, such as remaining trouble-free despite vibration and shock. These matters should be pretty much solved during the initial examination and concept design stages. Naturally, if it breaks there's a problem, but in addition to that, having too much room to move is also an issue from a design viewpoint.

Here, let's check how properties changed within the temperature range. I'm writing this in February 2014. I recently heard a news story about how the temperature had fallen below -30 ℃ in Japan's northernmost island of Hokkaido. But in summer, you will hear news stories of how the temperature topped 40 ℃ in Shikoku. Even in a small country like Japan, temperature variation spans -30 ℃ through to 40 ℃, so a motor must be able to perform properly within that range. Let's check how performance varies at 20 ℃ ±40 ℃.

The magnet and coil are among the parts most powerfully influenced by the motor. The temperature coefficient of a residual magnetic flux density Br of a neodymium magnet is said to be -0.11%/K and we know at variation of ±40 ℃, the Br will change by ±4.4%. Similarly, the coil's electric conductivity temperature coefficient is said to be 0.38%/K and at ±40 ℃ variation, we discover that it changes ±15.2%.

The image shows how, when applied to a motor, differences in temperature change the torque constant and coil resistance value (Fig. 18). Say the initial temperature is 20 ℃, raising the temperature to 60 ℃ will increase coil resistance and loss, prompting the synergetic effect of reducing output and efficiency as the magnet weakens and causes the torque constant to drop. There is an impact on the torque constant, which is decided by magnetic strength, but we learn that there is significant change in the copper loss with a large temperature coefficient. Conversely, dropping the temperature to -20 ℃ raises the Br and lowers the resistance, leading to expectations of the properties enhancing.

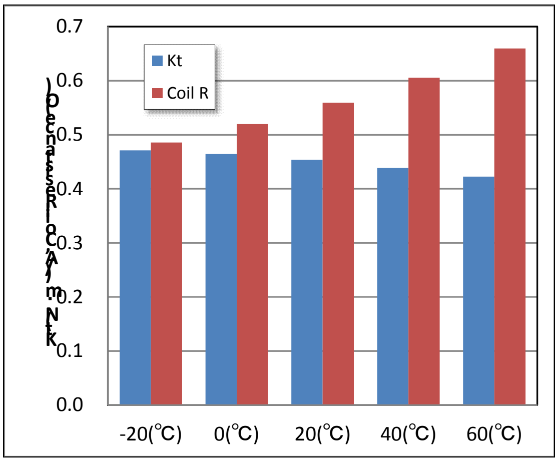


Fig. 18 Temperature Variations in the Torque Constant and Coil Resistance

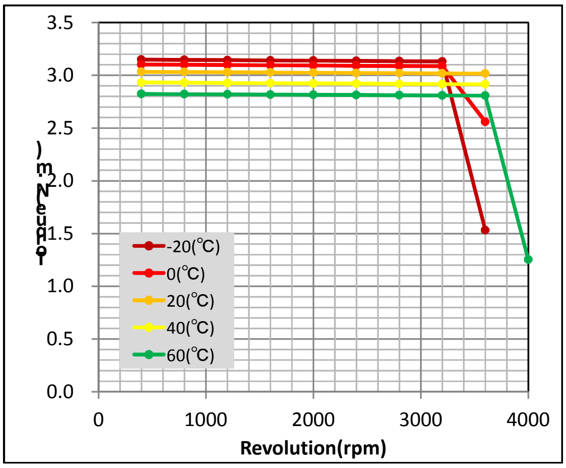


Fig. 19 Speed-Torque Characteristics and Temperature Differences

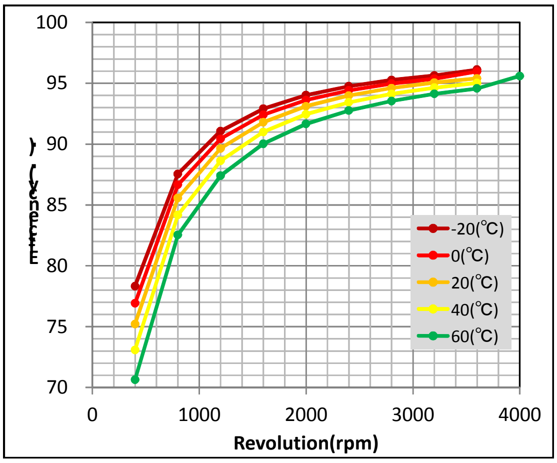


Fig. 20 Speed-Efficiency Characteristics and Temperature Differences

Next, let's check what kind of an effect occurs on motor properties. Looking at speed-torque characteristics, the torque constant has decreased, enabling a check at peak current (Fig. 19). On the other hand, when the magnet's magnetic field weakens the induced voltage constant also goes down and revolves at high speed. With speed-efficiency characteristics there is a decrease in efficiency due to increased copper loss brought about by rising temperature (Fig. 20) This is especially so during output when copper loss is controlling, which keeps speed low and decreases efficiency, and we can see that 20 ℃ at 75 % efficiency will fall at 60 ℃ to 70 % efficiency.

The effect of this is being able to generate your own heat during actual operations. If trying to maintain motor output at a certain point, you can get caught up in the following sequence of events, which will dramatically raise the temperature. As temperatures increase, the motor temperature rises→decreased performance and efficiency→recovery through increased input→increased heat generation→motor temperature increases even further. It's really important to check whether performance exceeds objective indices at times of high temperature.

Did You Achieve What You Aimed For?

These detailed designs polish proposed designs. Did you easily satisfy requirements and get an idea about reliability and costs? If so, your design is now complete.

Though only examining a few designs, we reviewed each part of the concept design. Here are the changes (Table 4). We made slight improvements to operations as a result of our examinations. Most noticeable of these improvements was being about to reduce the size of the magnet, which was effective from the cost-cutting perspective.

Table 4 Concept Design and Final Design

Parameters	Concept Design	Finalized Design
Shaft Diameter	16 mm	20 mm
Core-Back Width	8 mm	7 mm
Magnet thickness	4 mm	3 mm
Resistance	0.559 Ω	0.504 Ω
Torque constant	0.454 N·m/A	0.434 N·m/A
Maximum Torque	3.03 N·m	2.90 N·m
Magnet weight	0.153 kg	0.118 kg
Total weight	2.24 kg	2.26 kg

Looking at the N-T curve and speed-efficiency characteristics, we lowered the peak torque in the final design from 3.03 N to 2.90 N·m and the efficiency has improved marginally. In addition, as there has been a decrease of at least 20% of the magnet, it's probably not a bad result (Figs. 21 and 22).

Of course, we've only examined one area for the purposes of this magazine, so with the actual design far greater scrutiny must be given to a lot of other areas. I don't think a single examination will lead to improvements of several percentage points, either. At best, it would probably be about 1%. But, just as an old saying goes that "little and often fills the purse," a 1% improvement in many items can be expected to improve the product several percent overall, so it's important to keep plugging away.

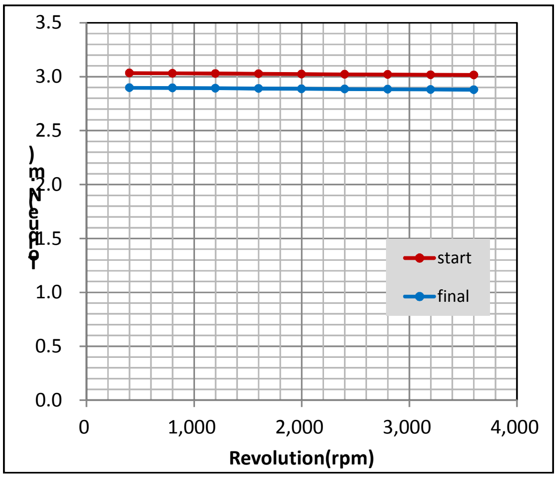


Fig. 21 N-T Curve in the Concept and Final Designs

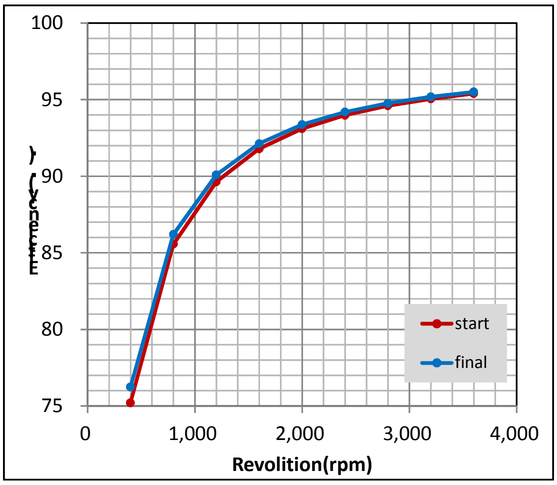


Fig. 21 Speed-Efficiency Characteristics in the Concept and Final Designs

Utilizing Feedback from the Prototype

When the final design is completed and designs all put in place it's time to move onto the prototype to verify answers. There are many things involved here, so they need to have a further countermeasure. TO make it easily understandable, you may get a calculation result where the design (analysis) says torque of XX N·m was output, but in actual machinery, there are times when it may have stopped at YY N·m. Looking into the cause of that difference can only be done as a countermeasure, but the process of formulating this is also an opportunity to examine what point a problem occurs or where an error arises, so this is extremely vital feedback. Once you have gained a grasp of what has gone wrong, it's possible to apply corrective measures to the examination method and improvements will become clear. Veteran designers have built up a multitude of this kind of experience. Putting aside in advance a few percent for performance margin and then spitting out a number toward the end while gambling on the material factor is perhaps one way that they tackle things with their accumulated know-how.

Series End

This article is the final issue in this series on our thoughts about the process of designing motors. I think the series probably gave those starting out in motor design or people simply interested in the issue some sort of an idea of what happens. Have these articles helped you with learning about how to use the tools in JMAG-Express Public or JMAG-Designer as part of the design flow?

However, when it comes to design, the contribution made by tools is pretty much on a par with an easy to use calculator. To make a good design undoubtedly requires a designer with a great sense of designing. Even if a designer chooses to get help from a tool, the tool alone will not be able to create a great design plan. Perhaps optimized design plans created with a combination of optimization software and magnetic field analysis software will still not be as good as a design plan cranked out by an experienced designer. But expectations of an even better plan are possible when a veteran designer uses optimization software, so beginners will always lose out to long-term designers regardless of the tools they may use. Consequently, the only approach for beginners to take is to throw yourself into learning and polishing your skills with constant production and eventually become a veteran designer in your own right. Please use JMAG-Express Public or JMAG-Designer as the venue to polish your skills and designing awareness.

(Yoshiyuki Sakashita)

Motor Design Course

What Happens when Torque Variations Arise?

The Motor Design Course focused on motor design, but this column picks up issues that could not be fully covered and looks at them while conducting a simple experiment.

In this issue, we will look at torque ripple. Cutting torque variation is an issue motor designers deal with in perpetuity. Unfortunately, we don't have enough design strength to be able to give you information that will work like magic or be like some secret plan to solve your problems. What we can do, though, is show you how to use JMAG to display torque variations in the hope it may provide you with a hint about how to devise measures to reduce torque variations.

First, how does a motor generate torque? Have you ever seen torque (or electromagnetic force)? I haven't. Textbooks will say things like "Lorentz force generates torque" or "Maxwell stress makes it build up," but all this is only ever in a book. I'm always thinking about how I've never actually seen torque. I can't get rid of this feeling even now, but JMAG gives us the opportunity to see something close to torque being generated.

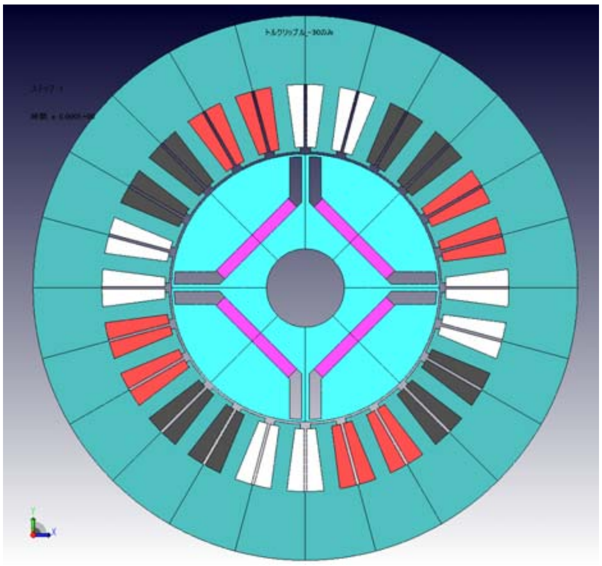


Fig. 1 Motor Model Geometry

We ran an analysis on an IPM motor to observe how torque variation is generated (Fig. 1). The analysis was on a model with 4 poles and 24 slots and an electric angle of 90 deg. Passing a 3-phase sinusoidal current through a current results in a torque waveform like the one shown in the image (Fig. 2). Looking at the torque waveform graph shows significant dips in torque variation every 15 degrees and you can predict there will be a slot pitch effect. If you quickly come to the conclusion at this point that it's going to be possible to predict slot pitch effect, you're not going to see the torque ripple. We need to dig a little deeper.

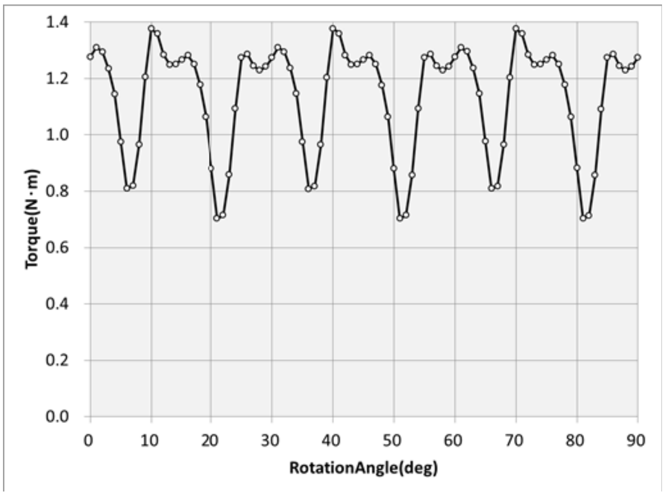


Fig. 2 Motor Torque Variations

Check the motor flux lines and nodal force in a state where torque is being generated normally (Figs. 3 and 4). What stands out is just how extremely large size of the rotor and stator attraction force (the radial direction force). But, the radial direction force doesn't contribute to torque, so we can ignore this.

Looking at the electromagnetic force vector from the teeth tip shows that in the teeth near the boundary between the motor's N and S poles and joined to the torque there is significant force in the θ direction. There is apparently no effective torque being generated from teeth in other positions.

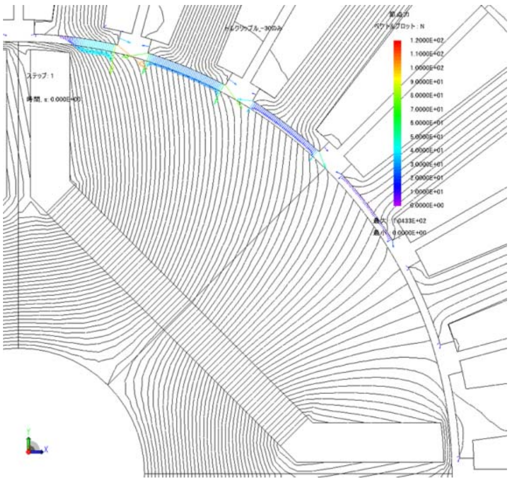


Fig. 3 Magnetic Flux Lines and Nodal Force Vector Plots in a Motor

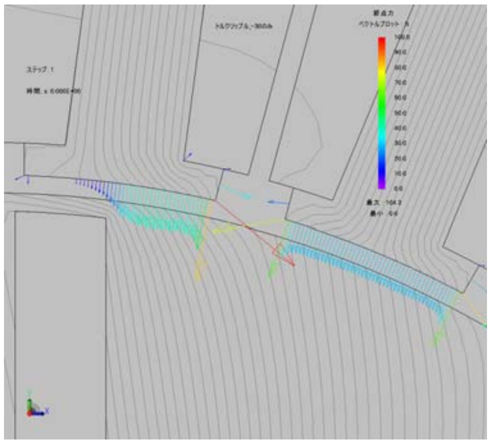


Fig. 4 Magnetic Flux Lines and Nodal Force Vector Plots in a Motor (Enlarged)

Next, set the torque conditions for each tooth and observe the torque for each tooth (Fig. 5).

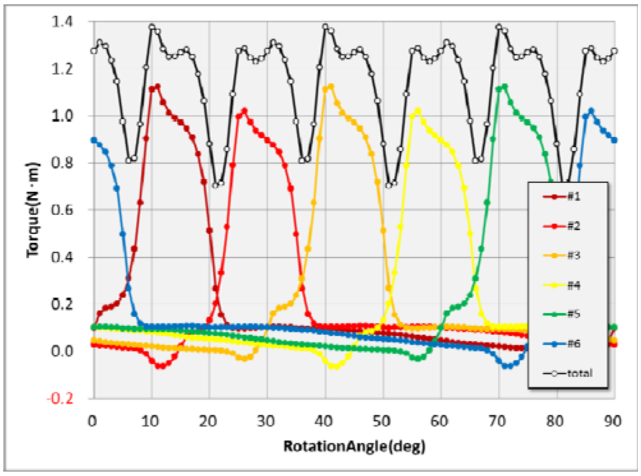


Fig. 5 Overall Torque Waveforms for Each Teeth (Electric angle half period)

You can make a really rough estimation from the image stemming from the nodal force vectors, but plotting these on an actual graph is extremely tough. Solving using this information shows a significant portion of the torque generated in the motor comes from a single tooth. It's easy to see that switching the tooth in conjunction with rotations will continue generating torque. Focusing on a single tooth gives the impression that torque is generating over a roughly 15-degree stretch of the 90-degrees making up a half period of the electric cycle, leaving the remaining 75 degrees essentially idle. The "roughly 15 degrees" here is important because torque variations in this "roughly" area are large and we learn that troughs are created when overlapping doesn't work well.

Let's take a slightly more detailed look at torque waveforms. This is an enlargement of the 0-15-degree area equal to a single teeth pitch phase (Fig. 6).

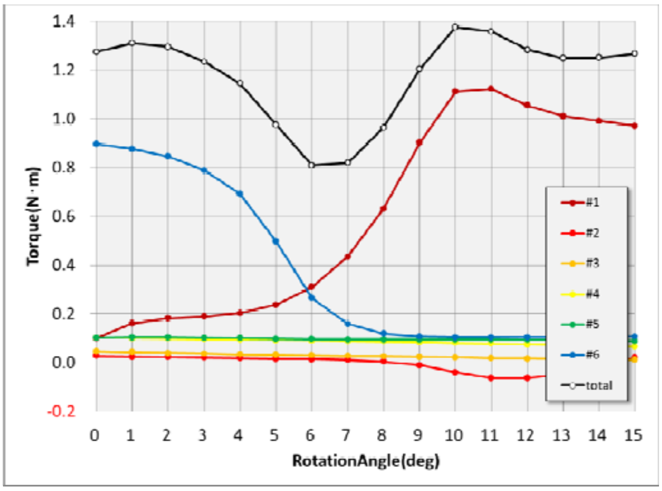


Fig. 6 Overall Torque Waveforms for Each Teeth (1 slot)

The black line represents the torque the rotor generates. At revolutions of 0 degree, the torque controls #6 (blue), exists with #5 (green), #1 (brown) and $4 and only slightly generated in #2 (red) and #3 (orange). As speed increases, torque in #6 drops dramatically and increases drastically in #1, but we learn that as the increase and decrease are unequal torque variation is generated.

It goes without saying that we are led to the conclusion that the key to reducing torque variations lies in skillful overlapping. It would be ideal if it was possible to increase the peaking time, but I think the reality would be more likely to involve imagining measures that fill in a trough created by breaking down a peak. A measure like this would have an effect on actual model geometries like slots, rotors or detailed geometries thus it would be impossible to examine without using a high-precision finite element analysis (FEA) like JMAG-Designer.

We used an IPM motor in this case. I think results would turn out differently with an SPM or concentrated winding (fractional slots). I'm really interested to see what would happen with an induction motor. This is a real test for designers, but we expect that designers will be able to put JMAG to use to come up with solutions.

If there is a topic you would like us to cover in this column, we will try to deal with it. If there is a topic you would like us to cover in this column, we will try to deal with it.

E-mail：info@jmag-international.com

Solutions

Issue 1 Thermal Analysis Solutions

Thermal design of a motor now places increasing importance on compactness and high density, both for the motor and its periphery, forcing electrical circuit designers to always keep in mind issues such as heat generation and heat release.

This article will be the first of a series of two articles about basic solutions needed as thermal countermeasures, centering on JMAG thermal analysis functions and taken from the viewpoint of an electrical circuit designer's approach to thermal design.

Introduction

Necessity of Thermal Design

Development of permanent magnet motors using rare earth magnets representing neodymium magnets has greatly accelerated miniaturization and higher density of motors as they have a comparatively higher density of energy than motors using ferrite magnets of the same volume. Motor miniaturization and density growth is the cause of increased heat generation density resulting from various types of losses such as copper loss, and countermeasures for heat dissipation and cooling accompanying this are sought. Rare earth magnets, in particular, have comparatively weak heat resistance and need measures to prevent heat reduction. One valid method as a measure is to use a thermal analysis simulation to confirm temperature increases or heat transfer circuits in each part and examine these for thermal design.

This article will focus on the heat phenomenon in motors and describe over two issues the thermal analysis solutions JMAG can deliver. This first article will describe thermal analysis solutions JMAG provides for motor's heat phenomena and the modeling required for that.

JMAG Thermal Analysis Functions and Thermal-Electric Field Coupled Analyses

JMAG does not only have magnetic field analysis functions capable of highly accurate calculations of eddy current or iron loss, it also provides thermal analysis functions handling heat transfer phenomena. For this reason, evaluation considering both magnetic circuit design and thermal design is possible.

JMAG Thermal Analysis Functions

JMAG's thermal analysis functions analyze based on Fourier's heat conduction equation. This enables accurate solution of the phenomena when the analysis subject's thermal path is caused mainly by heat conduction. Generally, thermal paths in actual machines also include fluid like air, but heat transfer phenomenon caused by liquid is by convective effects and they differ from heat transfers. When an analysis is dealing with a fluid, heat dissipation to the liquid becomes important. JMAG's thermal analysis functions make allowances for the effect of heat equivalent circuits on liquids. From the following section onward, we'll examine how to look at thermal analysis models with a view to using them in JMAG's motor thermal design.

Thermal-Magnetic Field Coupling Analysis

A heat source necessary for a thermal analysis can be obtained from a loss in a magnetic field analysis. That's why a thermal-electric field coupled analysis is considered to be the fundamental analysis when magnetic field and thermal analyses are to be conducted simultaneously. A coupled analysis will respond to phenomena, provided a choice between linking one-way from a magnetic field to thermal or a two-way link between the thermal and magnetic analysis.

This is an analysis method applicable to a one-way coupled analysis when you can ignore the temperature dependency of the analysis subject (for example, when the effects are ignored in a region where the material properties focuses on the temperature change). In a magnetic field analysis, loss in the heat source is calculated just once and the thermal analysis refers to that result while computing the temperature calculation to be analyzed. Alternatively, if sufficient time has passed since the start of the phenomenon, it can also be used by focusing on the temperature distribution after the transient state has shifted to the steady state. Many motor thermal analyses examine temperature distribution after attaining the steady state and this method is used comparatively more often.

In a two-way coupled analysis, when the temperature dependency of the material properties of the analyzed subject cannot be ignored, this analysis method can be applied. Thermal analysis passes on temperature distribution to magnetic field analysis by obtaining temperature distribution based on the loss from magnetic field analysis. In magnetic field analyses, the analysis is carried out based on temperature variations by updated material properties, then obtained loss is passed on to the thermal analysis again. This process is repeated in both directions (Fig. 1).

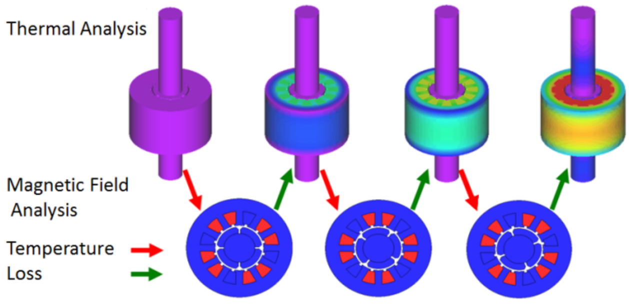


Fig.1 Image of two-way coupling

Modeling for Thermal-Magnetic Field Analyses

This section will look at the magnetic field and thermal analysis models needed for a thermal-magnetic field coupled analysis.

Handling Loss

A thermal analysis uses loss obtained from a magnetic field analysis as its heat source. Consequently, the subject that generates loss in a magnetic field analysis needs to be modeled.

In that case, what about the motor heat generation source? Representative examples of heat sources can be given in the form of coil copper loss, core loss, magnet eddy loss or stray loss in the case or shaft. When examining efficiency, these is a need to examine the contribution of each of these types of losses in detail, but when it comes to thermal issues, coil copper loss and eddy loss in the magnet are important.

Looking first at copper loss, the absolute amount of copper loss is the greatest of all heat generated within the motor and because the heat generation region is limited to the coil, the heat generation density increases. Therefore copper loss becomes the largest heat source contributing to the thermal analysis of the motor. However when it comes to the actual copper loss itself, it is possible to estimate manually if the drive current is known by using the specifications of the coil and calculating the heat amount generated after passing through DZC resistance.

Next, loss generated in magnets is generally lower than that found in copper loss at absolute amounts, but if the heat dissipation is poor due to low volume magnets air in the magnet core or exterior, it can lead to irreversible demagnetization due to concentration of heat generated in the magnet. Be especially careful when there is strong influence of the slot harmonics in the high rotation region. For this reason, heat generation sources must be examined together with copper loss.

As far as iron and stray loss are concerned, while the loss generation region is large, the absolute value is not as large as that for copper loss and the loss density per unit volume is not as large as that for the above two items, thus they are rarely a critical issue for the heat generation source (Drive regions in a high efficiency motor may see the amount of copper and iron loss generated be about the same level).

Examining Material Properties

In a magnetic field analysis, magnetic properties of the magnetic material of the core or magnet is necessary but electric conductivity of magnets and such are also necessary when working with eddy currents. Material properties may change significantly depending on the temperature so a temperature table with each material's data is necessary. Heat generation from copper loss will change the electric conductivity in the coil, so also confirm this in a temperature table. However, for the coil's electric conductivity, for the purposes of modeling, the value given is not that of electrical conductivity itself, but one allowing for coil resistance.

In a thermal analysis, as well, thermal conductivity and specific heat needed for the analysis also have temperature dependency. Confirm the effect of material properties for the temperature changes envisioned and prepared thermal materials data allowing for temperature dependency.

Geometry Modeling

This section will give a description of modeling the geometry needed for a thermal-magnetic field coupled analysis.

1. Differences in Modeling Subjects

When modeling a geometry, an important point to keep in mind is that there is a difference in the parts needed for a magnetic field analysis and thermal analysis. In a magnetic field analysis, the magnetic materials (rotor/stator) that form the main magnetic path, the magnet providing the source of magnetic power and the coil are the main subjects for modeling. Items such as the case covering the model, cover and shaft are not part of the main magnetic path and as they each generally have only a little loss they may be eliminated from the modeling. Generally, the time constant in electromagnetic phenomena is smaller than that of thermal phenomena, therefore the significant change in temperature required in a coupled analysis to occur, an extremely large number of steps may be needed to achieve that mark. When modeling, simplify parts as much as possible to avoid having an effect on accuracy.

As will be stated later, results from a 2D model magnetic field analysis can be used in a 3D model thermal analysis. This enables choosing between a 2D analysis and a 3D analysis for the motor geometry to be used in a magnetic field analysis of a motor. In a radial gap-type motor, the main magnetic path is in the lamination face and leakage flux from the ends can be ignored, a 2D model cut from a cross-section is convenient and effective.

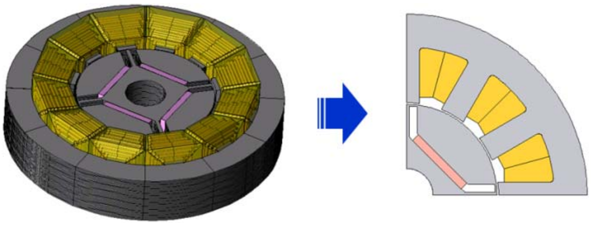


Fig. 2 Density Model (left) and Simplified 2D Model (right)

In this thermal analysis, the necessary parts on the thermal path are modeled. Due to this, parts like the separated case and shaft excluded from modeling in the magnetic field analysis are needed (Fig. 3). Materials like resin that are used to fix the coil in place must be modeled on the thermal path. An increase in parts included in the thermal analysis also decreases the symmetry of its model compared to an electromagnetic field analysis. For instance, a magnetic field analysis may have a 1/4 model circumferential direction, but a thermal analysis needs a 1/2- or full-model. Take care when examining the models.

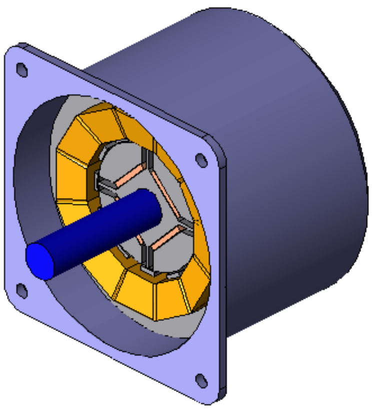


Fig.3 3D Model with case, shaft

2. Air Region Modeling

In a magnetic field analysis, modeling of the air region as an important magnetic path is also necessary, but in a thermal analysis the air region is generally not modeled as a mesh. In this, air is a liquid, which transports the heat, not as a heat conduction, but as a liquid movement caused by convection because a heat transfer equation cannot be applied. But considering heat dissipation, there is a need to incorporate the effects of fluids in some way.

The heat transfer boundary condition is used in these situations. In the heat transfer boundary condition, specify the heat transfer coefficient and reference temperature (liquid temperature). The heat transfer coefficient changes drastically depending on factors including the type or state of liquid. Natural convection air is set at a value of about 10 Wm/℃. For forced convection the value is around 1000 Wm/℃, which is tens of times larger than natural convection [1]. In a thermal analysis, the method of obtaining this value has a powerful influence over results, so selecting the value is one of the biggest worries involved in moving forward with an analysis. The heat transfer coefficient shows a comparison of the distance between the liquid's thermal conductivity and boundary face to the reference temperature. That means the larger the number the faster heat will move from the boundary face due to convection and the distance to attaining the reference temperature will be shorter. The heat transfer coefficient is required to be measured at various points from the boundary face, so if experience enables gaining a grasp of the distance, estimate rough values to use. As for other estimation methods where you know the distribution amount of the heat transfer coefficient from the thermal liquid analysis, you will be able to use those results as the boundary condition.

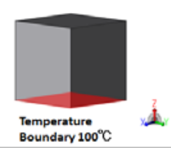
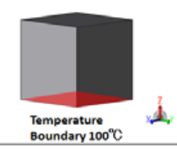
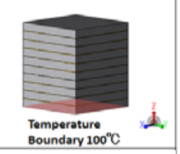
3. Modeling Laminated Steel Sheets

Laminated steel sheets are used in many cases with the stator and rotor that form the motor's main magnetic path, but magnetism of these sheets is in the in-plane direction, which is easy for magnetism to pass through, while magnetic flux has difficulty in passing through the laminated direction. In analyses a laminated structure model allowing for magnetic anisotropy is needed. In a magnetic field analysis, do not model for each sheet, but instead model in bulk, incorporating an insulation layer and lamination factor and allowing for magnetic anisotropy in the in-plane and lamination directions.

In a thermal analysis model, the laminated layer structure should allow for the anisotropy of the in-plane and lamination directions in regard to thermal conductivity. JMAG's thermal analysis function has a function that enables setting different thermal conductivity vales for laminated- and in-plane directions when using bulk geometries.

To confirm the anisotropic effect, verify using an analysis model assuming composed of several electromagnetic steel sheets. Isotropic, anisotropic and precise models, each with different thermal conductivity properties, make up the analysis models and used to confirm the temperature distribution in the laminated direction when the temperature boundary at the lowest face is set at 100℃. Specifications for each of the analysis models are shown in Table 1.

Table 1 Analysis Models for Verifying Lamination Anisotropy

Isotropic Model	Anisotropic Model	Precision Model
		
Material Property Specify the isotropic thermal conductivity of the magnetic material **Boundary Condition** Temperature boundary of 100℃ in the bottom Other faces are heat transfer boundaries	**Material Property** Specify different thermal onductivity for XY plane and Z direction depending on the lamination factor **Boundary Condition** Temperature boundary of 100℃ in the bottom Other faces are heat transfer boundaries	**Material Property** Specify the thermal conductivity of insulation and magnetic material for each layer **Boundary Condition** Temperature boundary of 100℃ in the bottom Other faces are heat transfer boundaries

The analysis results showed in the precision model temperature difference followed the lamination direction and was about 20 ℃, but in the isotropic model is was only about 5℃ difference, so temperature distribution situations differed (Fig. 4 left and Fig. 5). The anisotropic model temperature difference was about 20℃ (Fig. 4 center and Fig. 5) with the temperature distribution tending toward the same as that seen in the precision model (Fig. 4 right and Fig. 5).

From these results we learned that the same methods can be applied in modeling electromagnetic steel sheets and thermal analyses as used with material modeling in magnetic field analyses.

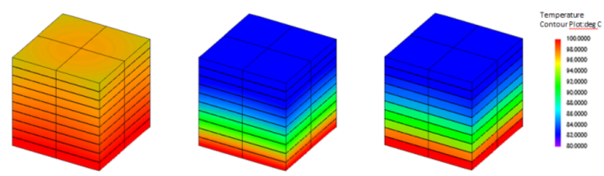


Fig.4 Temperature Distributions
(Same temperature contour scale)
From left: Isotropic Model, Anisotropic Model, Precision Model

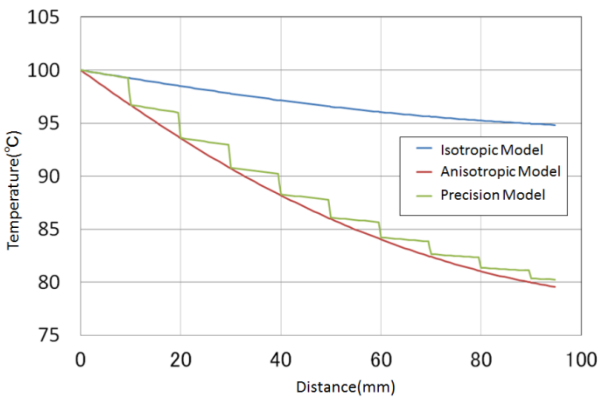


Fig.5 Temperature Variations Following the Lamination Direction
In the precision model, insulation layers with large heat resistance had a great temperature gradient.

For the model above, since constant temperature boundary is set for the ends of the lamination direction, it is set so that temperature difference is easily outputted in the lamination direction and difference in modeling of laminated structure is directly reflected upon the case. For an actual motor, the coil is usually winded along the lamination direction of the iron core and is believed that heat transfer will occur in the lamination direction of the iron core touching the winding and that it will be heated almost uniformly regardless of each layer. However, as you will see in the next section with the example using motor iron core of the concentrated winding, although it is not as much difference as it was for the above model, both isotropic (Fig.6 left) and anisotropic models (Fig.6 right) have difference in temperature distribution of lamination direction as you can see in both models.

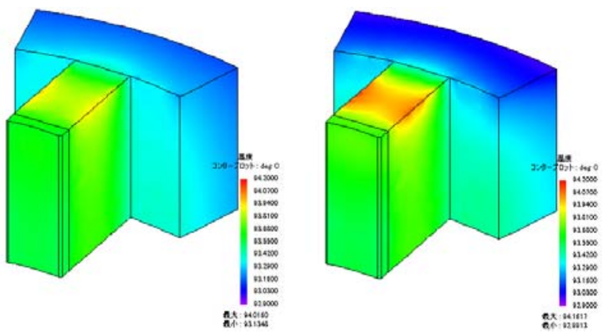


Fig. 6 Temperature Distribution in an Isotropic Model (Left) and Anisotropic Model (Right)
Isotropy and Anisotropy represents the difference in thermal conductivity

4. Coil Modeling

When the coil geometry can ignore the skin and proximity effects due to the drive frequency component, there is no need to model the wire by the unit and the coil can be handled as a single block. When it comes to coil blocks, except in large machines where wire diameter is generally less than the skin depth, model suitably for the relationship between frequency and wire diameter in a rotating machine, but in a thermal analysis because the coil cross-sectional direction and coil direction differ to make the heat transfer easier, meaning allowance must be made for anisotropic thermal conductivity to respond to this. The coil is coated with varnish, epoxy resin or some other resin material to prepare the geometry and here we envisage sufficient resin coating and no gaps between the wires. Heat generated from the coil must pass through the resin material in the cross-section direction for thermal conductivity. Because of this, effective thermal conductivity in the cross-sectional direction requires the heat resistance of the coil and resin material to be comprised sequentially. In the coil direction, the coil is distributed consecutively with the resin material and a mosaic lump, effectively comprising a parallel heat resistance. The schematic picture of equivalent heat resistance（Fig.7）.

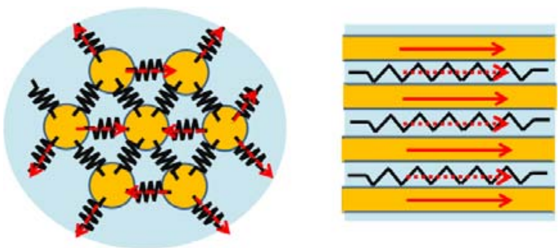
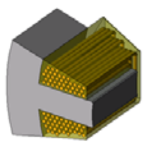


Fig.7 Impression of Anisotropic Heat Resistance in the Coil
Heat resistance distribution in the cross-section direction (left) and wire direction (right), with the coil showed in amber, resin in blue and an arrow pointed toward the heat flux

JMAG's thermal analysis function can be set for anisotropic thermal conductivity for bulk coil models with the coil in the cross-section direction and wire direction. To confirm the anisotropic effects, we compared two types of coil models, one is a bulk model to express coil in bulk and the other is a precise model for expressing coil in wire by the unit. Bulk models will respond to isotropic models where the isotropic copper thermal conductivity is specified for the coil and the wiring lamination factor and are divided into an anisotropic model specifying thermal conductivity where the cross-section and wire directions are different (Table 2). We conducted an analysis using direct resistance obtained from the coil geometry for each coil in a precision model and specifying the loss value obtained when running direct current of 10 A.

Table 2 Analysis Model for Coil Anisotropic Verification

Isotropic Model	Anisotropic Model	Precision Model
		
Specify isotropic thermal conductivity of copper for the winding. As for the core, specify the anisotropic thermal conductivity appropriate for the lamination factor.	Specify different thermal conductivity for vertical and cross-section directions of the winding depending on the lamination factor.	Specify thermal conductivity of Epoxy Resin and copper to both winding and resin material.

First, in the precision model it's possible to see as forecast the high temperature distribution within the coil, with a maximum temperature of 99.9 ℃ (Fig.8 left). Taking a more detailed look at distribution shows temperatures are high toward the exterior from the center of the coil. This is a model geometry with a circumferential direction periodic structure and therefore the circumferential direction resin cross-section has thermal insulation, but because heat in the inner coil can flow into the teeth and the outer coil is through to have high temperature distribution. As for the core wrapped in coil, the temperature on the top of the lamination direction will be hotter（Fig.8 right）.

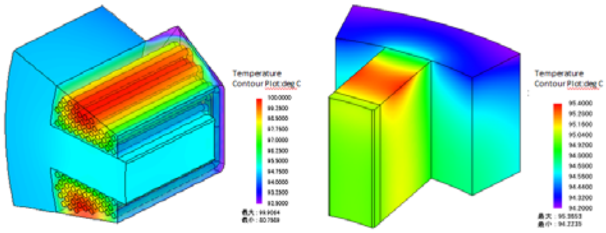


Fig.8 Temperature distribution for precise models (left: with winding, right: only core)

Next, we can see that the presence of coil anisotropy in bulk models can lead to significant differences（Fig.9）.The isotropic model temperature distribution is close to being uniform and the maximum temperature was 94.2℃（Fig.9 top left). Consequently, we can see discrepancy in both the results of the distribution, maximum temperature and precision model. In addition, compared to the temperature distribution in the core of the precision model, we can see results closer to being uniform for the lamination direction (Fig. 9, top right).

On the other hand, anisotropic models are identical to precise models in temperature distribution of winding and the maximum temperature is 99.3℃in the winding part (Fig.9 bottom left). Even for comparisons only in the core, the maximum temperature difference was 1.2℃ (Fig.9 bottom right). It can be confirmed that the temperature distribution has improved by accounting for anisotropy.

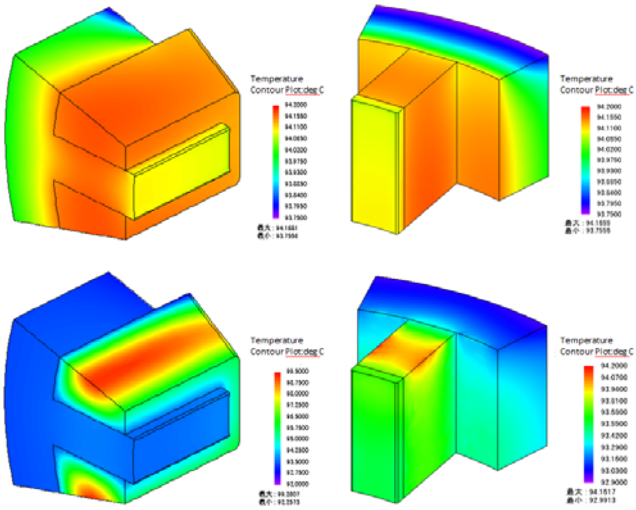


Fig. 9 Temperature Distribution in an Isotropic Model (Top) and Anisotropic Model (Bottom)

5. Narrow Gap Modeling

As for motors, very narrow gaps can be found in the boundary part of a magnet slot and magnet or divided core. These may have effect as magnetic resistance in magnetic field analysis, and in magnetic field analysis, they will be accounted for in the analysis by setting the magnetic gap condition in place of mesh modeling.

There are times when modeling is necessary as thermal resistance in thermal analysis. For example, for gaps between the magnet and magnet slot, compared to the core, glue with extremely low thermal conductivity is coated and modeling accounting for heat dissipation from the magnet is necessary. This, however, makes modeling with mesh difficult as thickness of glue is generally thin.

In that case, use the contact thermal resistance condition (Fig. 10). You will need to know the thermal resistance value to set beforehand for the contact thermal resistance condition, but since it is not necessary to model the space in-between, generating mesh is not necessary (once the geometry and thermal conductivity is defined, it is possible to estimate thermal resistance similar to the calculation of electric resistance by manual calculation).

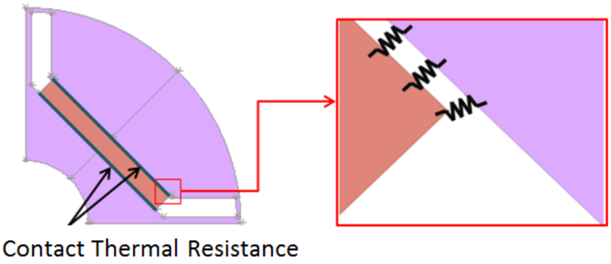


Fig. 10 Modeling via Contact Thermal Resistance (Image)
The opening of the right figure is an image and it is continuous on the mesh

As regards to heat generation from the rotor, magnet display comparisons of the case that glue was modeled using contact thermal resistance and a case not accounting for the modeling of the glued part. (Fig.11). When the glued part is modeled with contact thermal resistance, as opposed to not modeled, the heat dissipation will be poor and the magnet part will increase in temperature (the temperature increase for the rotor itself will be less sensitive). In addition, contact thermal resistance does not require modeling with mesh but since the magnet and magnet slot will be connected through thermal resistance, discontinuity amounting for the temperature difference caused by contact thermal resistance to temperature distribution in the boundary will occur (Fig.12).

As for modeling of the rotor, there is a need to account for the effect caused by heat dissipation through the rotational motion of the rotor, but due to the limitations of paper, we will leave that topic for the next volume.

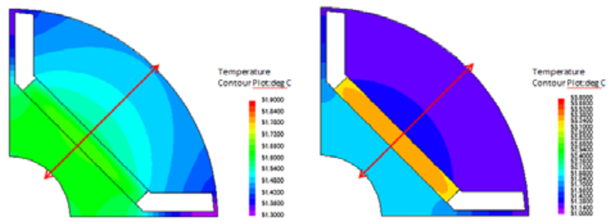


Fig.11 Difference in presence of glued part due to contact thermal resistance in the modeling process
Arrows in the figure represent the reference position in the section graph of Fig.12

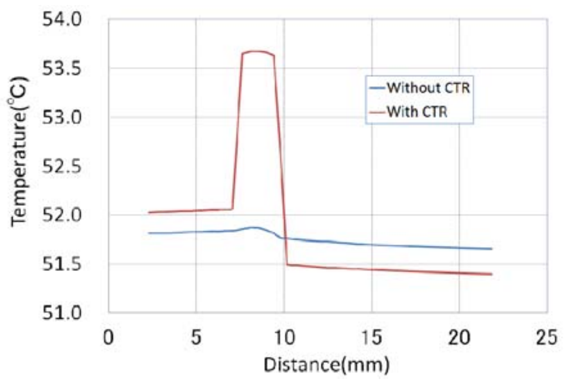
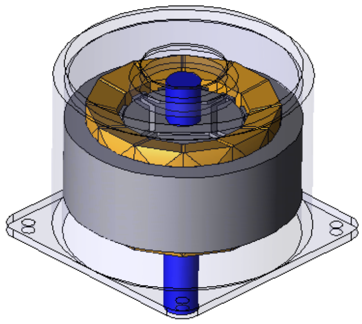


Fig.12 Difference in presence of glued part due to contact thermal resistance in the modeling process
The discontinuity seen in 7.5~10mm of the figure was caused when a magnet passed by（CTR：Contact Temperature Resistance）

Study of Thermal Equivalent Circuit

As we have touched on in the modeling of the air region, in the region of the heat transfer equation, there is no need to directly model liquid as a finite element model. Use the thermal equivalent circuit when applying thermal conductivity analysis to a target composed of many parts separated by space. Liquid parts not modeled as a finite element model will be identified as thermal resistance that connects parts on the thermal equivalent circuit. Each part will be represented as a node connecting thermal resistance components. Also, thermal equivalent circuits not only represent liquid as node, but also parts that are not modeled as analysis parts. For instance, a case is not represented as a finite element model, but heat dissipation is initiated through the case and the boundaries of the outside air region, the effect of the case will be represented on the thermal equivalent circuit. Displays the example of a thermal equivalent circuit as opposed to Fig.13 where the model is simplifying the case (Fig.14).

As this figure shows, the thermal equivalent circuit allows you to qualitatively take into account fluid effect or the effect from parts difficult to be formed as a thermal analysis model of finite element. We are going to introduce the thermal equivalent circuit again in the next issue.



Simple model simplifying the case part of Fig.13
The case set as semi-transparent is not modeled using mesh

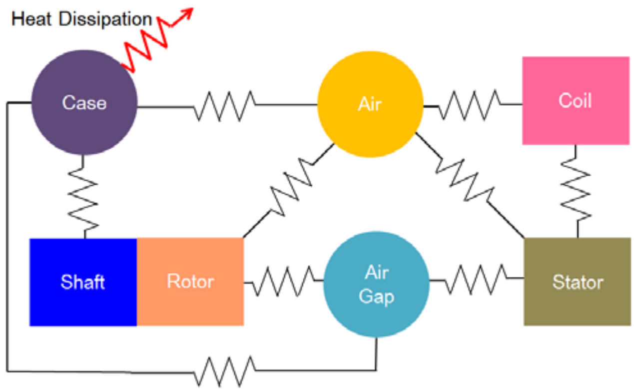


FIg.14 Thermal equivalent circuit model compatible with Fig.13
Components shown as a square are infinite element models. Components shown as a circle are defined only on the equivalent circuit, and are not mesh models.

Lastly

This issue introduced basic thought for modeling in terms of thermal analysis solutions in JMAG by focusing on the thermal phenomenon of motors. I hope you were able to find interest and depth in thermal analysis for users planning to work with analysis through seeing modeling unique to thermal analysis and handling based on the homogenization method in terms of laminated steel and winding. Furthermore, to proceed with advanced thermal analysis, it is sometimes necessary for simulation such as thermal liquid analysis, however, even in the range of heat transfer analysis, depending on the model, you can obtain useful information for the evaluation of motor thermal design.

In the next issue, I will introduce an actual case study using the model designed in this article and its results. In addition, I hope to introduce solutions coupling with other thermal liquid solvers and JMAG's magnetic field analysis. Check it out.

（Takayuki Nishio）

Reference Material:

[1] Masahiro Shoji. "Dennetsu-kougaku(Heat Transfer Engineering)" University of Tokyo Press

JSOL Activity Report

Recent initiations with iron loss analysis

Iron loss evaluation in magnetic field analysis has had many issues. From our recent initiations with this issue, we would like to introduce our method of initiations with iron loss evaluations of direct current bias magnetism.

Introduction

Iron loss evaluation in magnetic field analysis has had many issues and we have also been working hard for a solution. Our main focus is covered in the September 2013 issue of the JMAG Newsletter.
https://www.jmag-international.com/jp/newsletter/201309/04.html

In Fig. 7 of this article, the factor thought to influence iron loss is higher harmonics. This time, we will report our recent initiations with higher harmonics of direct current bias magnetism.

Initiations with a new iron loss calculation method

Questioning the conventional iron loss calculation method

The conventional JMAG iron loss evaluation method is an extension of Steinmetz's empirical law. Steimetz's empirical law formulates an empirical equation of the iron loss of alternating current excitation and has been widely used as it expresses the iron loss of AC electrical equipment well. We have also used this method for evaluating iron loss of permanent magnet synchronous motors and transformers. For instance, the "Harumi Project" introduced in the September 2013 issue of the JMAG Newsletter also uses the Steinmetz's empirical law in evaluating iron loss of permanent magnet synchronous motors and has shown good results of consistency with the actual measurement.

However, we have always questioned whether Steinmetz's empirical law can be applied in the case that the carrier or space harmonics of PMW invertors are superimposed. In Steinmetz's empirical law, hysteresis loss and the coefficient representing eddy current loss is determined by the iron loss properties measured with the Epstein law. The law will be measured by applying the magnetic flux density of alternating current that has a time average of 0 (in other words, it is not DC bias magnetism and will be expressed as around the zero point) and the parameter will be determined here but there is no solid reason that it will be applied to superimposed harmonics to basic harmonic components or direct current components. Realistically, it may not be at a level of concern. We initiated in iron loss calculation methods that applies to arbitrary waveforms that are not sinusoidal excitation clear around the 0 point.

New calculation method of iron loss

When it comes to a method that also applies to an arbitrary waveform, I felt the need of a calculation method that adapts more to the generation of iron loss, rather than empirical law. Iron loss is composed primarily of hysteresis loss and eddy current loss. Hysteresis loss is a loss that is caused by the magnetic hysteresis phenomenon of magnetic material so I thought it would be necessary to model the magnetic hysteresis phenomenon. In addition, eddy current loss is generated from the induced current evoked by a steel sheet produced by the magnetic flux that changes over time; however, the flow of induced current is affected by the thickness of the steel sheet and the permeability of the nonlinear, so there is a need to work with complex phenomena. After research of calculation methods, I considered the following two methods.

1. Hysteresis Modeling

As a method to model the magnetic hysteresis phenomenon, I focused on the isotropic vector play model. Since it rigorously works with magnetic hysteresis, I predicted it would be applicable to direct current bias magnetism as well. I will show the method of iron loss evaluation using isotropic vector play models (Fig.1). First, I did not use the isotropic vector play model directly for the magnetic field analysis, and instead used it for evaluating iron loss in the post-processing of the magnetic field analysis.

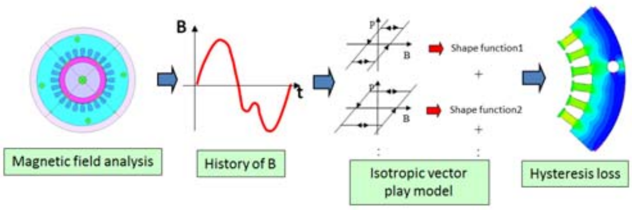


Fig. 1 Hysteresis iron loss evaluation through hysteresis model

2. Lamination Analysis

As mentioned earlier, for the case of an arbitrary excitation waveform, the eddy current distribution of the depthwise direction of the steel sheet is thought to be complex. To work with magnetic field analysis of the phenomenon, the magnetic steel sheet must be divided across the subdivided elements in the depthwise direction and a 3D analysis must also be run. Generally, 3D analysis takes a lot of time. Therefore, as post-processing of 2D analysis, I focused on the method of calculating eddy current loss accounting for the distribution of the steel sheet depthwise direction (lamination anaylsis) (Fig.2).

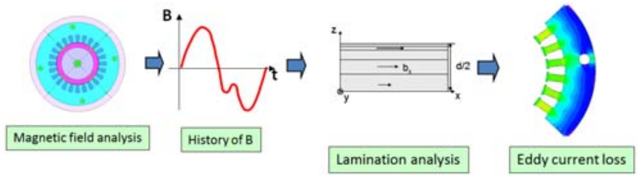


Fig. 2 Eddy current evaluation with lamination analysis

Data necessary for calculation and measurement status

Lamination analysis can be run if there is knowledge of the thickness and electric conductivity of the steel sheet. On the other hand, when working with a hysteresis model, symmetric loops are necessary (Fig.3). The iron loss properties of Epstein's law used by Steimetz's empirical law have been standardized as a measurement method and is also in magnetic steel sheet catalogs so it should be easy to acquire. On the other hand, while symmetric loops are difficult to acquire, there was a need to measure and prepare for future users. So before measuring, I decided to look over the graphs of some papers in detail and use them for verification. For 2013, in a joint research with Prof. Koji Fujiwara of Doshisha University Electrical Machinery & Apparatus Laboratory, we measured the symmetric loops of magnetic steel. This is how the measurement went (Fig.4). In order to measure a high magnetic flux density (approx. 2T), there was a need of winding an excitation coil of approximately 1000 turns for the test piece (Fig.5).Furthermore, since we had to wind in a ring shape, this turned out to be quite a heavy task. Please imagine cutting the tube of a plastic wrap and winding coil around it, using it as a bobbin and piercing the coil through it while wrapping around it. We were able to make a test piece with the support of the students at Electrical Machinery & Apparatus Laboratory and we conducted the measurement.

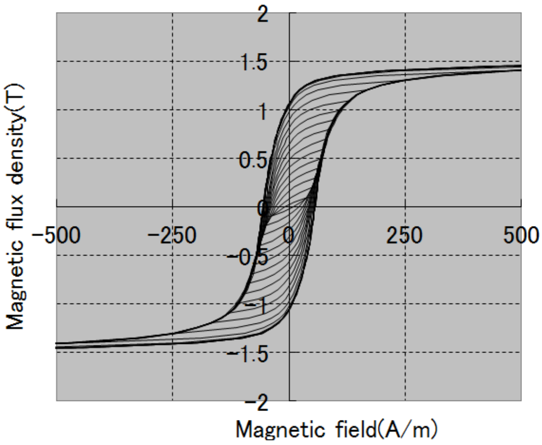


Fig.3 Example of symmetric loop

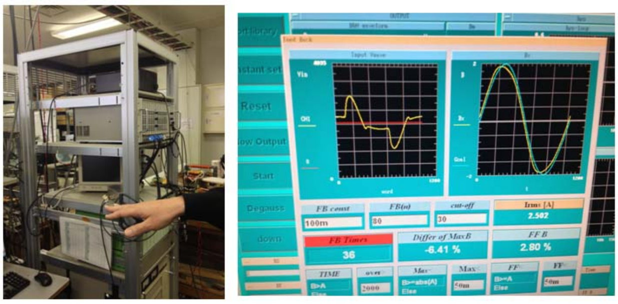


Fig.4 State of measurement

Fig.5 Test piece

If you are interested in having a feel of something difficult to measure, below, I have introduced what type of data to measure.

- For the target loop, the amplitude of magnetic flux density Bm should change every ΔB and measure N loops.
- If Bmax, the maximum value of magnetization distribution is the numberN necessary in the measurement, then N=Bmax/ΔB
- ΔB will determine how small of a loop can be expressed. A loop with amplitude less than ΔB/2 cannot be simulated.
- Measure frequency as low as possible so it does not have effect on the eddy current. Otherwise, measure several frequencies and extrapolate in 0Hz.

Verification with prototype

We evaluated iron loss using a prototype of a switched reluctance motor (SRM) to verify the effects of the method. Below is the actual prototype. Measurements were conducted in a joint research with Akatsu's laboratory of Shibaura Institute of Technology. How the measurement was conducted can be seen below (Fig.6).

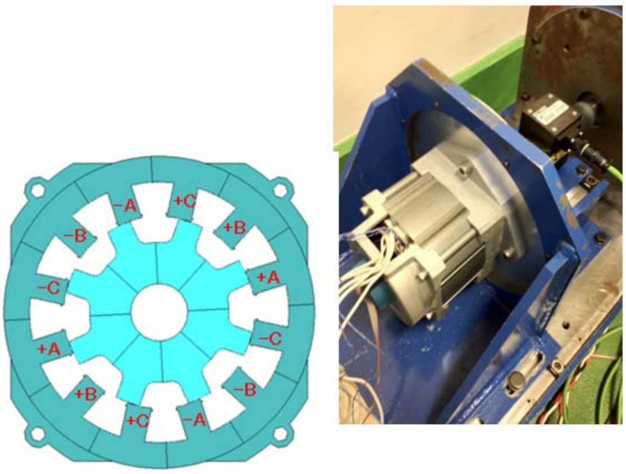


Fig. 6 Cross section of SRM and how the measurement was conducted

Excitation state of SRM

The reason why we chose SRM is because the magnetic flux density waveform of each part of the SRM is in a conventional direct current bias magnetism state (Fig.7). For this reason, it has been understood that compared to the former iron loss evaluation will be a difficult problem. Another similar problem is that for a rotatry machine, there is a rotor of a permanent magnet synchronous motor, and for a stationary device, there is a reactor that causes a direct current bias motion.

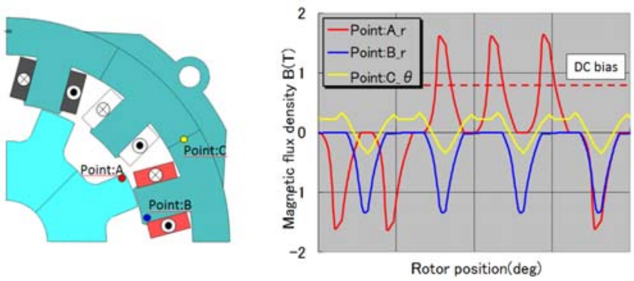


Fig.7 History of magnetic flux density for each part of SRM

Comparison of iron loss

Displays the results comparing the actual measurement, as well as the conventional and new Steinmetz's empirical law (Fig.8). With higher rotational speed, the traditional method will be underestimated but with the new method, a similar value to the measurement can be obtained. Since we were able to achieve results that we hoped to achieve with this method, we were relieved.

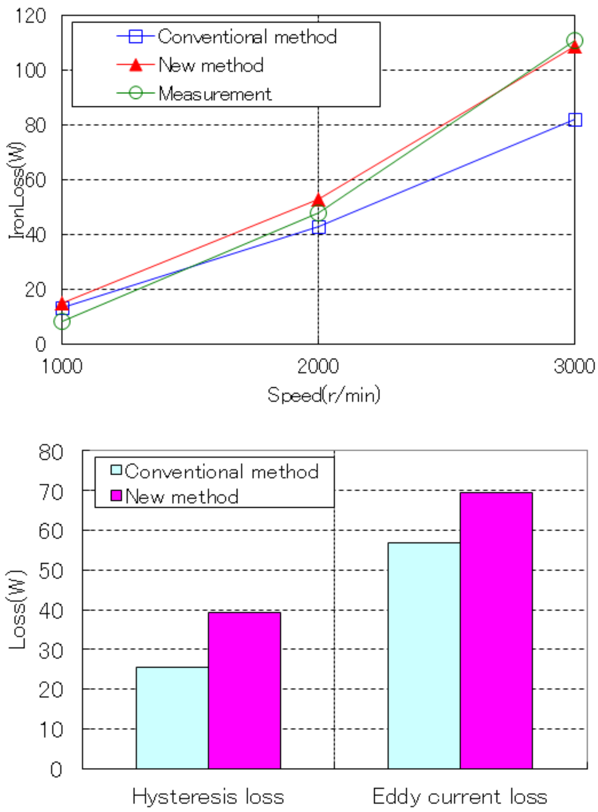
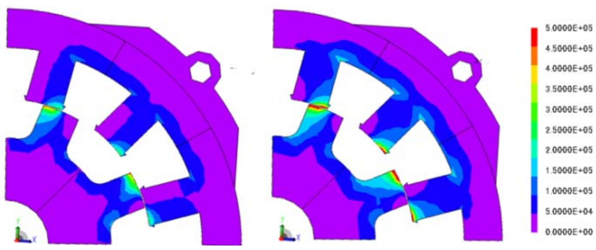


Fig.8 Comparison of iron loss

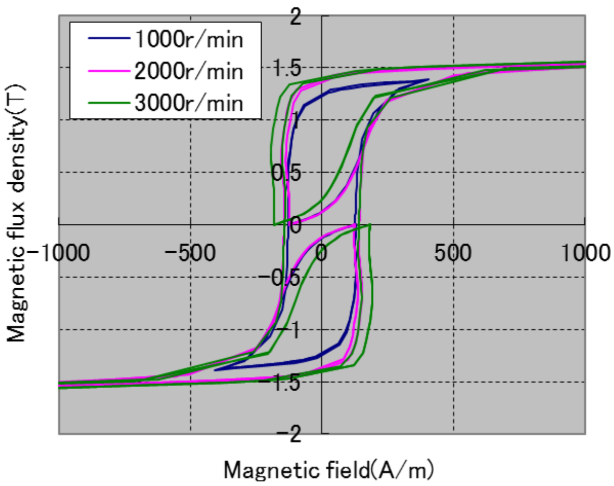
Example of results achieved

Displays the distribution of hysteresis loss obtained in the isotropic vector play model (FIg.9) and example of hysteresis loop (Fig.10). We were able to discover that it was depicting a complicated loop.

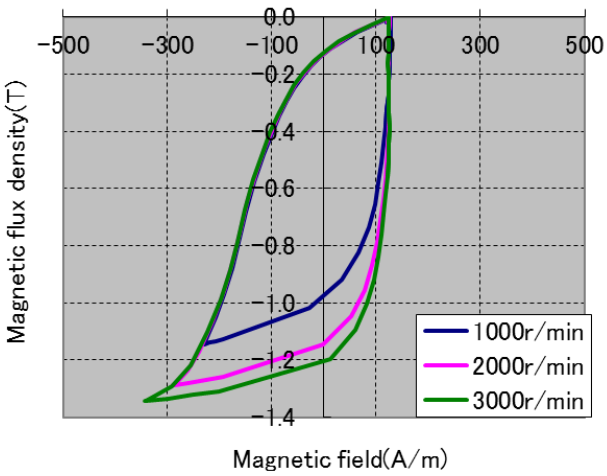


(a) Conventional method (b) Hysteresis model

Fig.9 Hysteresis loss distribution



(a) Point A



(b) Point B

Fig.10 Hysteresis loop

Future

To work with issues of iron loss evaluation of direct current bias magnetism, we have reported on comparing the incorporation of new iron loss calculation methods, evaluation of symmetric loops, and prior machine estimations. As a result, we have seen improvement in the accuracy of iron loss calculations in direct current bias magnetism. However, there are many issues left in iron loss analysis and we plan to look for a solution for these issues.

- In the magnetic field analysis, iron loss will be reflected as energy loss. Currently, we are evaluating iron loss with the post-processing of magnetic field analysis so there are no effects of iron loss in the torque or electric current. Evaluate the method where the iron loss has direct effect on the torque and electric current. For that reason, we are evaluating by removing iron loss from the obtained torque. We are considering a method to directly reflect the effect to torques and electric current in the magnetic field analysis.

-Working with the effect of residual strain and stress-dependency of magnetic properties as a function is possible but obtaining the data is difficult. For that reason, we are planning to measure the effect of magnetic properties on residual strain and stress-dependency in 2014. We are also planning to evaluate using a prototype.

-The details were not explained in this article but for a lamination analysis, excess eddy current loss (eddy current loss that cannot be evaluated in a regular induced current) is not contained so there is a need to account for correction coefficients. Various presumptions will be included so for a high-precision iron loss evaluation, a model adapting more to the principle of excess eddy current loss is necessary.

I would like to talk of future activities in another opportunity.

(Katsuyuki Narita)

Fully Mastering JMAG

Common Questions for JMAG

JMAG is used across a broad spectrum spanning from advanced research and development through to product production design and in educational fields.There may be many among those reading this JMAG Newsletter who still feel they haven't learned how to master it or perhaps feel a bit lost about how to set it up. When you come up against obstacles to using JMAG, of course there's always Technical Support, but don't forget there are also FAQs on our website that you can use to solve problems by yourself.

In this issue, we will select from those FAQs five questions that have been asked a lot recently. We have divided the questions into three categories of "Operation Methods", "Analysis Technologies" and "Troubleshooting", so please pick the category in which you are most interested.

OPERATION METHODS FAQ-934

Q1. I am running structural analysis and thermal liquid analysis using software other than JMAG. How should I conduct a coupled analysis with JMAG?

JMAG-Designer has coupling tools to work with Abaqus (SIMULIA) and Virtual.Lab (LMS) but is it possible to couple JMAG with other software? I am examining vibration anaylsis accounting for thermal liquid analysis and electromagnetic force distribution accounting for the loss distribution obtained in JMAG. What can I do?

A1. Coupling is possible using the multi-purpose file export tool. Convert the analysis results obtained in JMAG to a general-purpose file format and read the file through a desired CAE software.

JMAG-Designer provides two methods in coupling with CAE software other than JMAG.

The first method is to use the exclusive tool. This supports Abaqus (SIMULIA) and LMS Virtual.Lab (LMS). The second method is to convert the analysis results obtained in JMAG to a general-purpose file format and to use it in other software. CSV, Nastran, Universal file formats are supported.

If you have contacted them already, use the second method. As a file conversion tool, we have provided the multi-purpose file export tool. If it is a file format that is mentioned earlier and supported by the software, then the input file can be used.

OPERATION METHODS FAQ-93

Q2. Can files be exported as analysis results by element and node unit?

A2. Use the multi-purpose file export tool or result table function.

JMAG-Designer provides the multi-purpose file export tool and result table function to export files in text-format as analysis results for each node and element. Each function and advantage is introduced below.

Results are evaluated using the multi-purpose file export tool

Mesh information and analysis results are exported as files with the multi-purpose file export tool. Specify the output area for each part.

There are two advantages of evaluating results with the multi-purpose file export tool. The first point is that physical amounts can be mapped onto the mesh data produced by software other than JMAG. The second point is that it can export files as general formats used by software such as Nastran and Universal. If software other than JMAG supports the file format, it can be used directly as an input file.

Evaluate results with the result table function

The result table function outputs analysis results as files and displays tables through selecting elements and nodes in the result display of JMAG-Designer. Analysis results by each element and node can be easily checked in the GUI. Arbitrarily specifying the range of elements and node is possible, and is handy for evaluating specific areas.

See also FAQ-901 for the result table function.

OPERATION METHODS FAQ-936

Q3. How can I use the electromagnetic force obtained in the magnetic field analysis of transient response in the structural analysis of frequency response.

I am considering running vibration analysis in structural analysis software other than JMAG. I am hoping to use analysis results obtained in JMAG's transient response analysis for electromagnetic force that will be the excitation force. How can I convert time axis results of transient response analysis into information of the frequency axis?

A3. Using the multi-purpose file export tool, the results of the transient response analysis can be fourier transformed into frequency components. Set the [Output Type] to [Frequency Response Analysis].

With the multi-purpose file export tool, analysis results can be converted into output formats of static analysis, transient response analysis, or frequency response analysis. The option for converting results of magnetic field transient response analysis for the purpose of structural frequency response analysis will be introduced below.

Option settings of converting transient response analysis to frequency response analysis

Set [Output Type] to [Frequency Response Analysis] in the multi-purpose file export tool, and when analysis results of magnetic field transiet response analysis is specified in the input result file, the following option can be set.

-Target step: Set the time step, which will be the basic period during fourier transformation. When you wish to set the basic period for the analysis time of all steps of the magnetic transient response analysis, select all steps.

-Frequency order: Specify the actual order of output for the frequency components obtained in the fourier transformation. The order set from 0 order up until the frequency component will be exported and higher frequency components will be controlled. When the order has not been specified, frequency components of all order will be exported.

TROUBLESHOOTING FAQ-937

Q4. I get a warning message saying "Iterative calculation (ICCG) the magnetic field requires has not converged." Please tell me how to respond to this.

A4. Allow me to introduce three key points to check on this.

These three key points should be given priority when confirming whether convergence when running an iterative calculation using the Incomplete Cholesky Conjugate Gradient (ICCG) method has been good enough.

Iterative calculation using the ICCG method obtains distribution through magnetic flux density understanding a finite element method (FEA) matrix (actually, it finds the vector potential needed to obtain magnetic flux density).

Getting a message saying "Iterative calculation (ICCG) the magnetic field requires has not converged" is telling you that the maximum iterations set for an iterative calculation using ICCG will have a residual value below the convergence tolerance value.

First check the convergence details. Check the convergence status under ICCG by selecting [Convergence of place] under [Convergence Status] in the Solver Report. [Convergence List] [場の収束] If the residual is close to the convergence tolerance value, there is a possibility that the maximum iterations is too low. Improve this by increasing the maximum iterations. If the residual is considerably divergent from the convergence tolerance, confirm the following three items:

Change the ICCG solution method (For 3D analyses)

Three methods are provided for the ICCG solution method, and this includes the A method that doesn't add scalar potential to the conductor, the A-phi method 1 that adds it as unknown, and 2. A method is set as default. When the model includes calculation of eddy current, the calculation can be improved by changing settings for A-phi method 1 or A-phi method 2. A-phi method 1 is a relatively general calculation method. A-phi method 2 is a calculation method that has relatively high convergence, but there are also cases where there is no convergence for some models. Considering calculation speed, A-phi method 2 is recommended, but for the case that A-phi method 2 does not converge with the model, try A-phi method 1.

Mesh

Finite element method matrix solved with ICCG iterative calculation is dependent of mesh geometry. When the model includes aspect ratio with large (flat) elements, the iterative calculation may not fully converge. As for aspect ratios with large elements, it can be confirmed by highlighting the [Show Quality...] function in the right-click menu of the mesh, so consider changing the element size for improvement in quality. Improving the quality of mesh can result in improvement of convergence in the iterative calculation of ICCG.

TIme Interval（When the transient response analysis accounts for eddy current）

In transient response analysis accounting for eddy current, information one-step back is used for the iterative calculation of ICCG. For that reason, when the time interval is rough, errors may build up. Particularly in a transient state that has not achieved a steady state, the effect of errors will get larger. Improvement can be expected by setting smaller time intervals. On the contrary, when the time interval becomes extremely small, the amount of change from the previous step beomes extremely small compared to the absolute physical amount, so in order to accurately evaluate the difference, there is a need to minimize the number of errors.

TROUBLESHOOTING FAQ-938

Q5. I get a warning message saying "Nonlinear iterations has not converged". Please tell me how to respond to this.

A5. There are four points that need to be confirmed.

When nonlinear iteration calculations are not enough, in the order of priority, here are four points that need to be checked.

For nonlinear iterative calculations, run an iterative calculation that decides on the permeability when the magnetic properties of the material have nonlinearity. When the magnetic properties are linear, the permeability will be determined so there will not be a nonlinear iterative calculation. Nonlinear iterative calculations provide the two methods, Newton-Raphson and successive iteration.

Getting a message saying "nonlinear iteration has not converged" means that even though the set nonlinear iterative calculation of the maximum iterations is run, the residual value was not below the convergence tolerance value. First, confirm the details of the convergence state of the nonlinear iterative calculation. The convergence state of the nonlinear iterative calculation can be confirmed by each residual value from the iterative calculation in the [非線形の収束] of [Convergence List] in the solver report.

If the residual value gets closer to the convergence tolerance with more nonlinear iterative calculations, there is the possibility that there is not enough maximum iterations. Improvements can be expected by increasing maximum iterations. When there are more nonlinear iterative calculations and the residual value does not get closer to the convergence tolerance, and either stays static or has a tendency of increase, confirm the following four points.

Increase in precision of ICCG iterative calculation

Since ICCG iterative calculations are run for each nonlinear iterative calculation, when the precision is poor for ICCG iterative calculations, the accuracy of the nonlinear iterative calculation cannot be guaranteed. Confirm the three confirmation points of FAQ-937 when a warning message is outputted for the ICCG convergence state. When a warning message regarding the convergence state of ICCG is not ouputted, the accuracy obtained in the ICCG iterative calculation is not enough, and there is a chance that it may affect the convergence of the nonlinear iterative calculation. Attempting to increase accuracy by changing the convergence tolerance of the ICCG iterative calculation to a smaller value,may improve the convergence of the nonlinear iteration.

Confirm material properties

Nonlinear iterative calculations determine the permeability of the BH curve of magnetic properties. When changing the material to a linear material and the convergence of the nonlinear iterative calculation improves, there is a chance that the originally set magnetic properties are the culprit and the cause for poor convergence. Check to see that there are no flaws in the magnetic properties setting. When specifying magnetic properties in point sequence, the convergence of nonlinear iterations may improve when the slanted BH point sequence is set to decrease steadily.

Circuit settings

When the model is a FEM conductor component connected to a voltage source component on circuit, set a switch component between the voltage source component and FEM conductor component and set the current flowing in the FEM conductor component on the first step to zero; this will improve the convergence of the nonlinear iteration.

Changing relaxation factor (Newton-Raphson)

For the relaxation factor, [Relaxation Factor 2] is set by default. However, for most analyses including diodes, please try relaxation factor 1 as it tends to be the more appropriate setting for the convergence of nonlinear iterative calculations. When using relaxation factor 1, specify a curve that does not include S in the nonlinear magnetic properties for BH data.

Technical FAQ on WEB

Also check the JMAG website for technical FAQ.

URL: http://www.jmag-international.com/support/ja/faq/index.html (User verification required)

The technical FAQ is a collection of actual questions from our clients so you might discover some new ways to use JMAG if you go through them. We regularly update out website FAQ. Use this together with the JMAG newsletter to make your analysis work more effective. Please don't hesitate to use JMAG technical support if you have any questions when using JMAG. We hope you will fully master JMAG!

(Kensuke Araki)

JMAG Product Partner Introduction

MapleSoft
MapleSim Connector for JMAG-RT

MapleSim is a system level simulator with excellent reputation. The richness of the library is especially worth noting, and it is a great honor for JMAG-RT models to be added to their expansive collection.

We asked MapleSim on their strengths and the advantages of coupling with JMAG-RT.

What are the unique features and strengths of MapleSim?

By incorporating the most recent progress in engineering design technology, MapleSim offers a modern approach to physical modeling and simulation. It dramatically reduces model development and analysis time while producing fast, high-fidelity simulations. MapleSim is a "white-box" Modelica platform, giving users complete flexibility and openness for complex multidomain models. With MapleSim, users create, analyze, and run system-level models in a fraction of the time it takes with other tools.

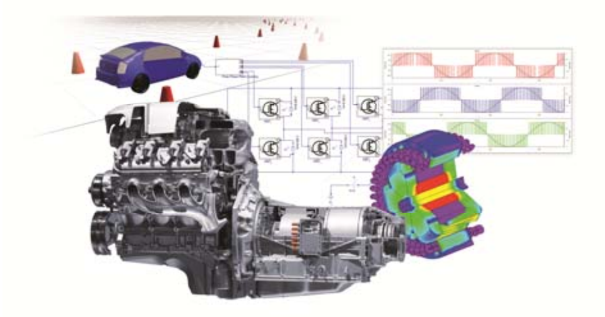
MapleSim, coupled with Maple, is a completely open environment, meaning that users are not restricted to built-in components or analyses. With its complete programming and analysis environment, they can run simulations, customize analyses or script entirely new ones, perform optimizations, develop advanced symbolic control laws, and investigate models in ways not possible with other tools. Users can even create custom components right from their unsimplified governing equations – the Maplesoft solution does all the work to incorporate them into the users' model. Whether they are running 100,000 simulations during an optimization or executing in real-time for hardware-and software-in-the-loop testing, the

Mr. Laurent Bernardin,
Executive Vice President and
Chief Scientist,
Maplesoft

model code must be fast. MapleSim's unique technology produces extremely fast auto-generated model code, and the code is completely royalty-free. Users can achieve real-time the first time, without sacrificing fidelity in the system-level models.

What value do customers get from coupling MapleSim and JMAG?

Incorporating JMAG motors and generator models into a MapleSim model allows users to study interactions between their motors and generators with other components of the final product. For example, in a hybrid-electric vehicle, the behavior of the battery, the internal combustion engine, the tires, and other elements of the car can have a significant impact on the performance of the electric motor. By incorporating all these diverse elements into a single system-level model, the engineer can better understand and optimize the behavior of the entire design, avoiding unpleasant surprises at the prototype stage.



Users can further refine their system model by implementing power output characteristics, such as torque and speed, based on inductance and counter-electromotive force information from the JMAG model. For example, users can incorporate non-sinusoidal fluxes and currents that are a result of asymmetric motor construction. Users can also produce highly optimized, auto-generated code of the entire system model, suitable for real-time execution and hardware- and software-in-the-loop testing.

Maplesoft Executive speak – Laurent Bernardin, Executive Vice President and Chief Scientist, Maplesoft

"Different tools are suited for different tasks, so it is vital that today's engineers have the ability to easily move from tool to tool as they work on their project, without incurring tremendous overhead costs in the process. By making it easy for engineers to use JMAG and MapleSim together, customers can take advantage of the strengths of each product to best meet their design challenges."

Applications

The MapleSim Connector for JMAG-RT is suitable for the development of any system in which the motor or generator is likely to have significant interactions with other components of the system. It is especially suited for electric and hybrid-electric vehicle applications.

The MapleSim Connector for JMAG-RT is available for purchase from the Maplesoft webstore, or by contacting the Maplesoft sales team.

Toll Free (Canada and USA): 1-800-267-6583

Phone: +1 519 747 2373

Fax: +1 5119 747 5284

Email: info@maplesoft.com

Outside North America:

http://www.maplesoft.com/contact/index.aspx

Event Information

Exhibitions and Events for April through June, 2014

JMAG will hold exhibitions at events both in Japan and overseas. Please stop by our booth and take a look at JMAG's activities. We would like to take this opportunity to introduce events and exhibitions for April through May, 2014

NAFEMS Deutschsprachige Konferenz 2014

A booth will be open.

Conference Outline

Host : NAFEMS Ltd

Dates: Tuesday, May 20 - Wednesday, May 21

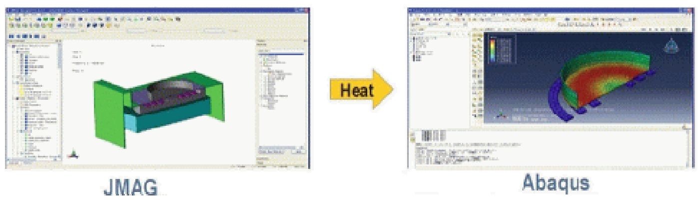
Venue : Kongresshotel Bamberg (Bamberg, Germany)

URL : http://www.nafems.org/2014/dach/

We will host an exhibition at a conference hosted by CAE Community international corporation, NAFEM.

At our JMAG booth, we will introduce examples using the small multiphysics function that has become easier to use with JMAG-Designer Ver.13. Even for magnetic field analysis users, multifaceted approaches can be taken using the feature that allows analysis accounting for both centrifugal force and the effect of heat in their analyses. Please check out the booth for case examples.

SIMULIA Community Conference



A booth will be open.

Conference Outline

Host : Dassault Systemes SIMULIA

Dates: Tuesday, May 20 - Thursday, May 22

Venue : Rhode Island Convention Center (Rhode Island, United States)

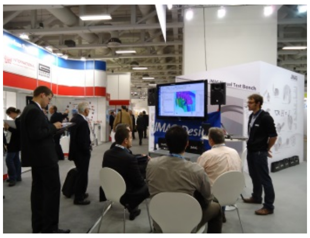
URL : http://www.3ds.com/events/simulia-community-conference/overview/

We will host an exhibition at SIMULIA Conference like last year.

At the JMAG booth, we will introduce case examples for clients considering mechanical design / thermal design simultaneously, and not just electrical design with magnetic field analysis. Unlike product evaluation with only magnetic field analysis as before, by combining magnetic field analysis with mechanical / thermal analysis, a far larger perspective of product evaluation is now possible. Please check the booth for case studies.

Coil Winding Berlin

A booth will be open.



Conference Outline

Host : i2i Events Group

Dates: Tuesday, June 24 -Thursday, June 26

Venue : Messe Berlin (Berlin, Germany)

URL : http://www.coilwindingexpo.com/berlin/

Coil Winding, known to be one of the world's largest exhibitions gather products related to coil such as winding machines, motor stators and insulating paper. Technicians from not only Europe, but from all parts of the world line up booths related to large transformers and wind generators.

The JMAG booth this year has expanded and will conduct demonstrations focused on case studies of motors and transformers. The booth presentation, which has received high acclaim over the years will also be at the booth. Please come and visit our booth.

At each exhibition, JMAG-Designer Ver.13.1, which is set for release early summer of 2014, will be unveiled.

We are planning to conduct exhibitions and seminars not only in the United States and Germany but around the world. Please check the website for exhibition details. We look forward to seeing you.

(Tomomi Igarashi)

Event Information

Event Report

Attendees report on events held from January to March, 2014. We hope you will attend our next event.

Cocktail during the BLDC AND IPM Machine Design course by AMT

Presentation of JMAG

Conference Outline

Host : Advanced MotorTech LLC.

Dates: Wednesday, January 15 - Friday, January 17

Venue : : Double Tree Hotel (San Francisco, United States)

URL : http://www.advancedmotortech.com/training.html

Lecture at a seminar hosted by Advanced MotorTech corporation.

On the second day of the event, there was an one-hour session on the process of mechanical design using Finite Element Analysis (FEA), and Dr. Keith W. Klontz did a lecture on JMAG. At the lecture, we introduced the new features of JMAG-Designer, along with design methods based on several case studies using IPM models.

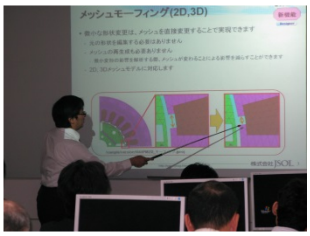
Attendees included engineers, researchers and designers, as well as graduate students from Europe.

The session was immediately followed by a cocktail reception and attendees had discussions about the lecture and improvement methods of the process using FEA. It was a productive time in discovering the potential of improvement in processes with FEA using JMAG.

(Dheeraj Bobba)

JMAG-Designer Ver.13.0 Version Upgrade Seminar

Host seminar



Conference Outline

Host: JSOL Corporation

Date: Tokyo: Wednesday, January 29

Osaka: Thursday, January 30

Nagoya: Friday, January 31

Venue: JSOL seminar rooms in Tokyo, Nagoya and Osaka

URL : http://www.jmag-international.com/jp/seminar/v-up/v-up130.html

We hosted a version-up seminar for for JMAG-Designer Ver.13 released December last year at our Harumi, Tosabori, and Nagoya office.

With over 40 attendees at all three 3 venues, the event turned out to be a success.

Up until two years ago, most of the attendees were JMAG-Studio users, but this time all the attendees were JMAG-Designer users and we were able to see that JMAG-Designer is becoming more common.

Some of the attendees had already downloaded the trial version of JMAG-Designer Ver. 13 and we received constructive criticism, as well as very complicated questions which we did not expect to hear at the release event.

Not only did we transmit latest information, but we were also able to obtain very useful feedback.

(Takauki Nishio)

Synopsys Saber Seminar

Presentation of JMAG

Conference Outline

Host: Synopsys (Japan)

Date: Friday, February 14

Venue: Nihon Synposys G.K. Tokyo Main Office (Japan: Tokyo / Setagaya-ku)

URL : http://www.synopsys.co.jp/events/seminar/saber/

Lecture at a Saber product seminar hosted by technical partner, Synopsys Japan Limited Company.

The lecture by Nihon Synopsys introduced new features of SaberRD, as well as noting the fact that plant models such as motors and actuators are in need of high-fidelity and that JMAG will be providing the solution.

JSOL introduced the coupling solution of Saber and JMAG-RT.

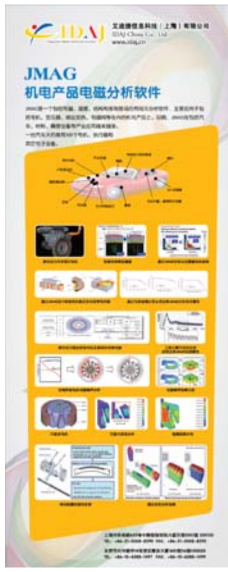
During the break after the lecture, we received many questions regarding JMAG-RT. Since it was a day of heavy snow, the attendees asked very specific questions as to how they would incorporate it into their designs, as well as serious questions as to its usability.

Through the seminar, I felt that we were able to inform the importance of high-precision motor models. I hope we were able to inform Saber users the usability of JMAG-RT in high-precision motor models as well.

(Yusaku Suzuki)

Web seminar of motor designs suitable for Chinese users

Hosted a web seminar regarding JMAG in China.



Conference Outline

Host : IDAJ-China Co., LTD.

Date: Friday, March 7

Venue: over the internet

URL : http://www.idaj.cn/news/show/id/3418 (only in Chinese)

JSOL hosted a web seminar with agency, IDAJ-China for the first time.

At the seminar, we provided hands-on experience of the motor design process using JMAG-Express. Suzuki, who has worked with electromagnetic analysis simulation for 15 years was the lecturer and his lectures, which includes his own experience, was responded with favorable reception.

The attendees were approximately 70 people and their occupation varied from researchers, designers, engineers, professors to graduate students. Since there was a high demand for hosting a web seminar, there were many attendees despite the lack in time from the date of recruitment to the event date.

With success and high reception, we are considering to host more web seminars in China.

（IVY Wang）

JMAG-Designer V13 New Function Seminar in Taiwan

Presentation of JMAG

Conference Outline

Host : Flotrend Corp.

Date: Tuesday, March 11

Venue : GIS NTU Convention Center (Taiwan: Taipei)

URL : http://www.jmag-international.com/event/2014/v13_seminar_taiwan.html

Our agency, Flotrend Corporation in Taiwan hosted a JMAG-Designer version upgrade seminar.

We had a demonstration of the features in JMAG-Express and introduced the new features of JMAG-Designer Ver.13.

We had approximately 40 attendees, and most of them were new to electromagnetic field analysis. Through the demonstration, we felt that the attendees were able to grasp the usability of JMAG.

We received many questions after the seminar, and we were able to feel the high interest in our software.

JMAG will continue to focus not only on Japan and will focus on international operation of business to meet the needs of globalization.

(Yusaku Suzuki)

Symposium Elektromagnetismus

Presented JMAG.

Conference Outline

Host : Technische Akademie Esslingen

Date: Tuesday, March 25

Venue : Reinhold-Wurth-Hochschule（Germany: Land Baden-Württemberg ）

URL : http://www.tae.de/de/kolloquien-symposien/elektrotechnik-elektronik-und-energietechnik/symposium-elektromagnetismus/

Approximately 110 attendees attended the10 seminars that were conducted in German at the session. There were many companies that handled electromagnetics and participants were primarily researchers, designers, engineers, professors, university students and graduate students.

At the seminar, we introduced case studies with JMAG, as well as simulation methods of electromechanical design. We were also able to spend an enjoyable time as we received many inquiries even after the seminar. We hope to have another seminar when the opportunity comes.

（Thiebaud PFISTER）

This New Year, we featured a report centered on exhibitions and seminars across the globe. JMAG will not only provide technical support but will also continually provide high-quality products to assist high-precision and high-efficiency for the customer,

In addition, Powersys Solutions, which is our agency based in the United States and Europe, have recently renewed their website. Please visit their website for frequently provided webinars.

URL:http://www.powersys-solutions.com/

Writer: Tomomi Igarashi