Core Loss Analysis of the Transformers for Vehicle Power Supplies

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Abstract :
Miniaturization makes the thermal design become an important issue for vehicle electronic power supply development. For efficient thermal design, it is necessary to understand the loss distribution. JMAG is used to analyze transformer and coil.
Generally, ferrite material has low electric conductivity and Eddy current loss is neglected. However under the condition of high frequency and high temperature, electric conductivity increase several fold, and become no more negligible. We improve core loss estimation method by dividing Joule loss caused by the Eddy current across the core.

Contents of the Presentation

1. Introduction of our company brochure and products
2. Background of Our Approach to Transformer Magnetic Field analyses
3. Accuracy Verification of the Coil Loss Analysis
4. Formulating New Methods and Verifying Their Accuracy
5. In closing

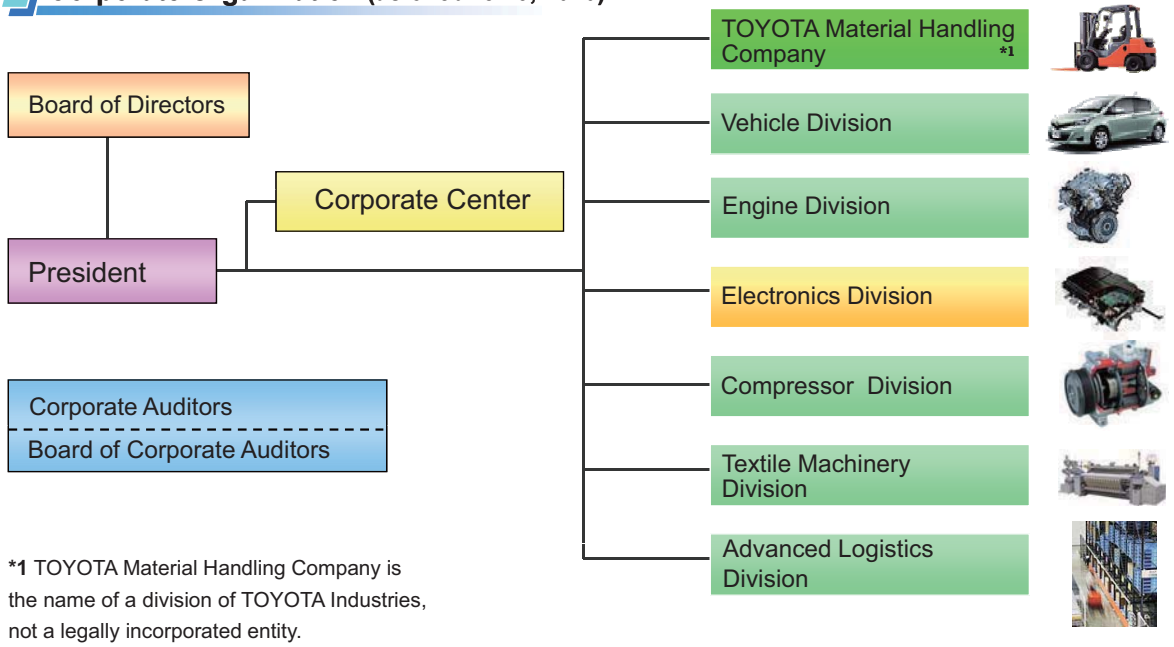
1. Corporate Profile

Company name	Toyota Industries Corporation
Established	November 18, 1926
Head office	2-1, Toyoda-cho, Kariya-shi, Aichi 448-8671 JAPAN
President	Tetsuro Toyoda
Business activities	Manufacture and sales of textile machinery, automobiles, materials handling equipment, etc. as well as logistics business, etc.
Capital	80.4 billion yen (as of March 31, 2011)
Net sales	1,479.8 billion yen
Operating income	68.7 billion yen
Ordinary income	73.9 billion yen
Net Income	47.2 billion yen
Employees	40,825 (as of March 31, 2011)
Consolidated Subsidiaries	162（Domestic: 38, Overseas:124）as of March 31, 2011
Affiliate Accounted for by the Equity Method	12（Only overseas）as of March 31, 2011

Note: Figures are based on FY 2011 consolidated business results.
(Amounts less than one hundred million yen of the figures are omitted.)

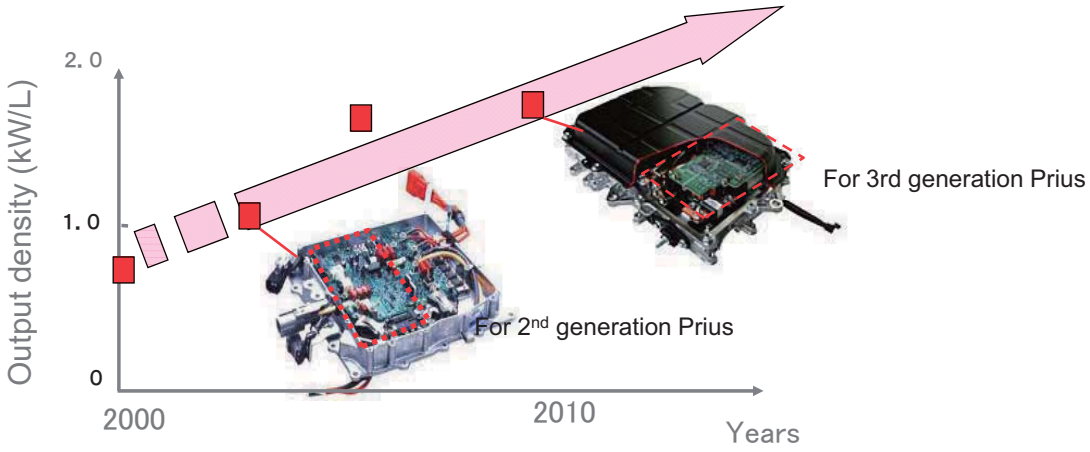
1. Corporate Organization

Corporate Organization (as of June 23, 2010)



*1 TOYOTA Material Handling Company is the name of a division of TOYOTA Industries, not a legally incorporated entity.

2. Product Trends and Development Subjects



Output density transition of DC-DC converters

Downsizing and power enhancing of vehicle mount power unit*1

⇒The fact that heat rises as output density (i.e. heat generation density) increases comes up as a significant technical issue.

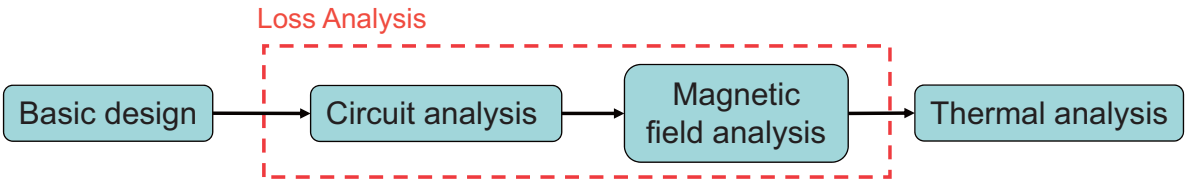
*The converter for Prius achieved an improvement of output power by 20% and downsizing by 30%, compared with old products.

2. Thermal analysis flow of coil transformer

Understanding the internal structures and loss distribution is vital for highly accurate thermal analyses.

⇨ Coil transformer uses magnetic field analysis for coil losses.

Comparing with theoretical calculations and actual measurements, it is possible to figure out the loss of each material, and prediction accuracy has been improved as well.



Thermal analysis flow of a coil transformer

2. Error cause of transformer loss analysis

Difference from the actual measurements

Geometry	Simplifications of geometries such as 2D models or integration of windings
Current	Difference from actual waveforms
Material Properties	Nonlinear characteristics of relative permeability and electric conductivity
Iron loss	Unevenness of the iron loss properties and nonlinear characteristics
Analysis Conditions and mesh settings	Mesh and convergence

*Nonlinear characteristics：dependence properties to magnetic flux density, frequency, and temperature.

⇨ We verified analysis accuracy with a transformer that does not account geometry differences and has a small number of coil turns.

2. Transformer Verification Result

Thermal analysis results based on the loss obtained from magnetic field analysis.

… The core temperature is lower than the actual measurement, by 22 deg!

Is the loss unexpectedly small due to “extra-definition range of the iron loss curve”?

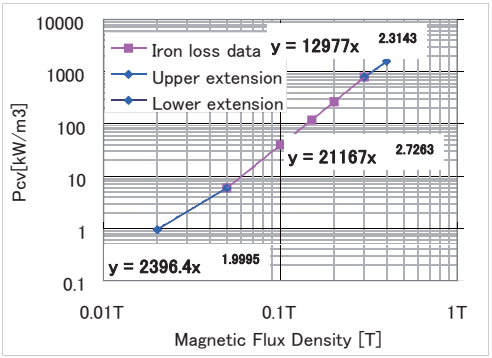
1. The calculation frequency refers to the extra-definition range of the iron loss curve.

The frequency definition range of the iron loss curve of material #1 is 5.000e+004 [Hz] to 1.000e+006 [Hz], but it refers to 1.060e+006 [Hz].

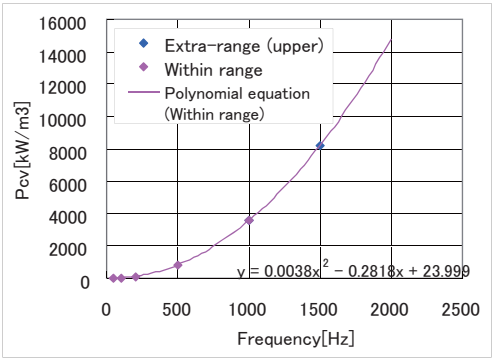
Solver : ironloss
Version : 10.0.0h
Code : 150041

The above is the analysis report alert message.
(I entered up to 1000kHz, the range mentioned in the catalog, but…)

2. Influence of the Iron Loss Data Range



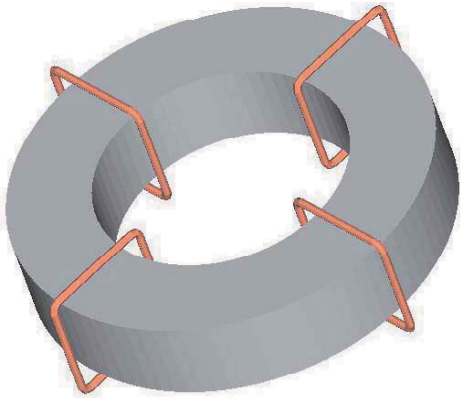
Iron loss density v.s. Magnetic Flux Density



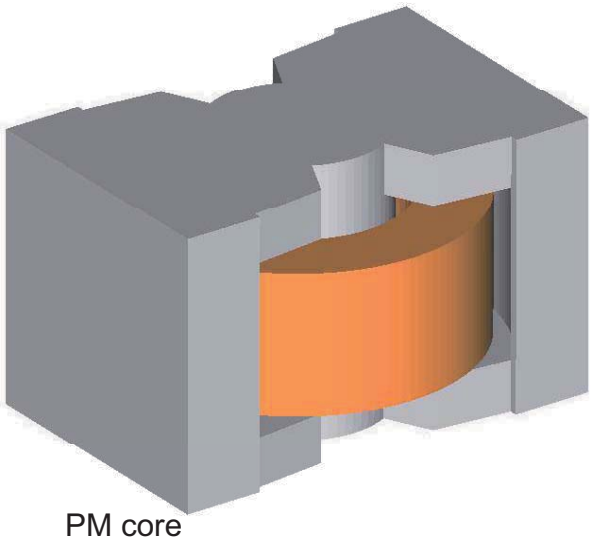
Iron loss density v.s. Frequency

We applied uniform magnetic flux density, and confirmed the extra-range handling.
⇒Factors of extra data range are extrapolated as well.

3. Accuracy Verification with Coils



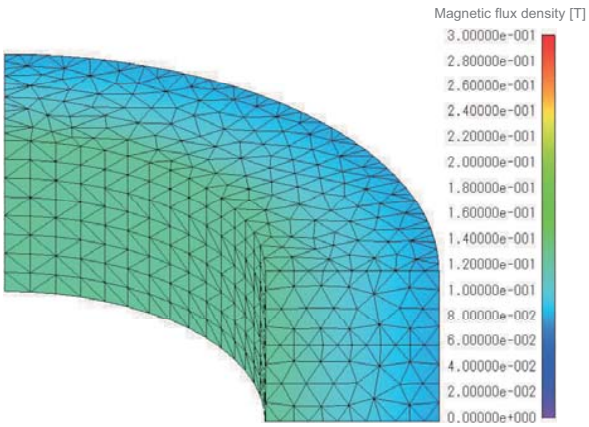
Standard ring core
(Geometry measured on catalog)



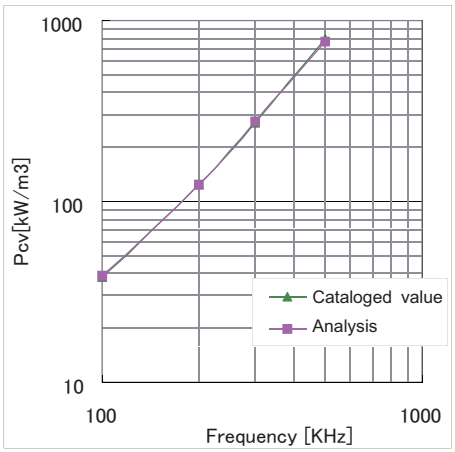
PM core
(Geometry measured on actual machine)

Comparison with the iron loss density data measured by a core material manufacturer.

3. Comparative Result of Standard Ring Cores



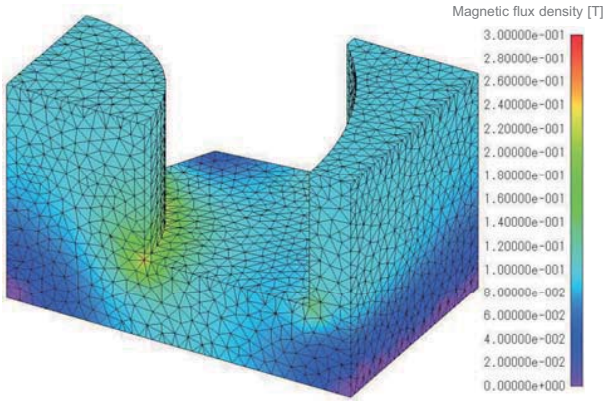
Magnetic flux density distribution @0.1T



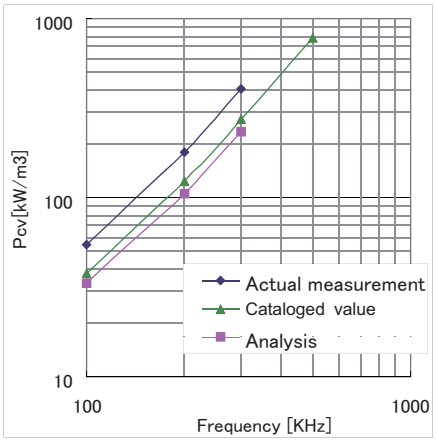
Comparison of iron loss density

With a standard ring core, the result matched the iron loss density characteristics that we entered.

3. Comparative result of PM cores



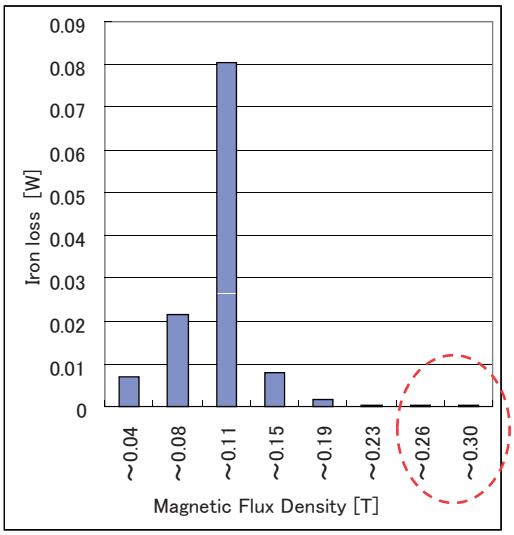
Magnetic flux density distribution @0.1T



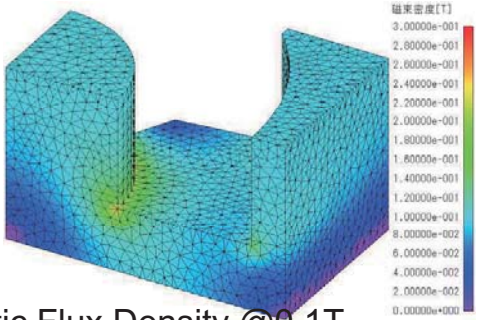
Comparison of iron loss density

With a PM core, the loss is 40% lower compared to the actual measurement.

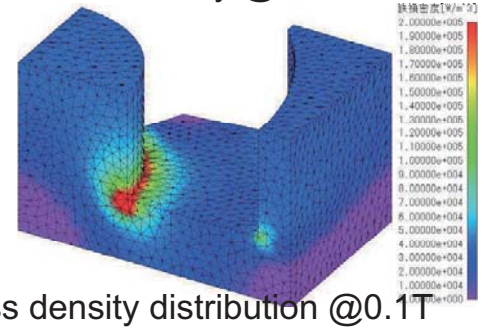
3. Influence by Fine/coarse of Magnetic Flux Density



Iron loss per magnetic flux density



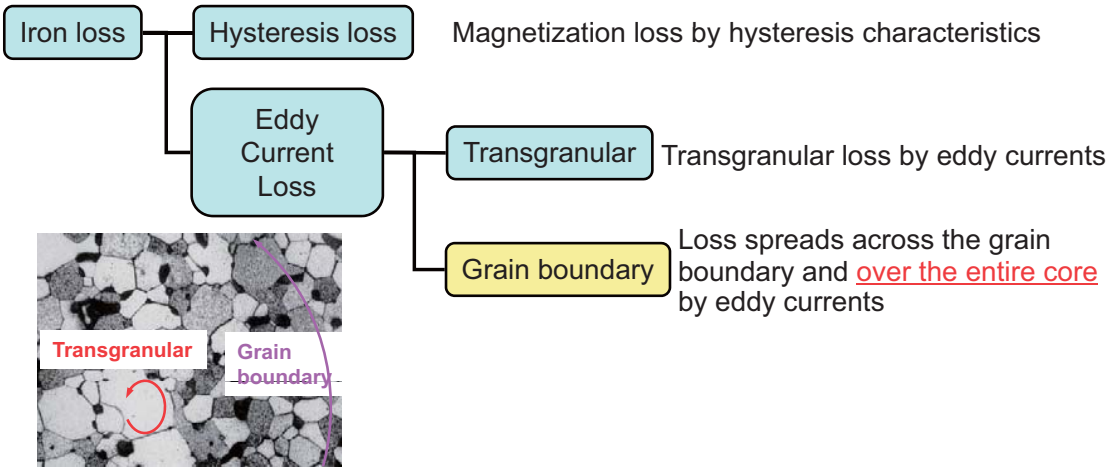
Magnetic Flux Density @0.1T



Iron loss density distribution @0.1T

The range of magnetic flux density is high, but it takes up a low portion of the entire loss amount.

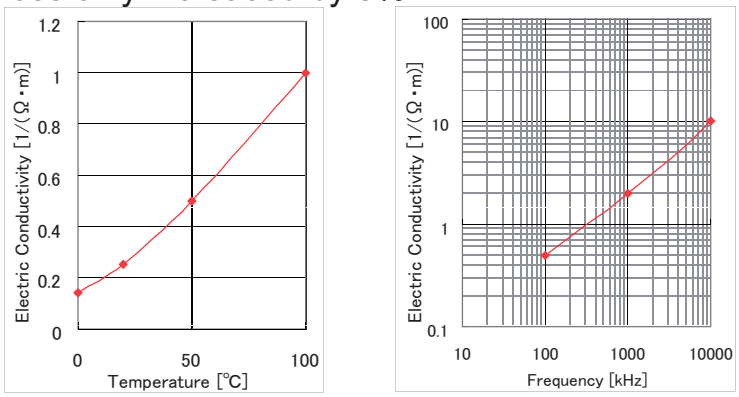
4. Breakdown of Iron Loss



Iron loss property data that is specified as material properties includes geometry dependent components.

4. Temperature and Frequency Dependence Properties of Electric Conductivity

<Challenge #1> We set the electric conductivity on the core, and calculated the Joule losses caused by eddy currents, but the loss only increased by 8%...



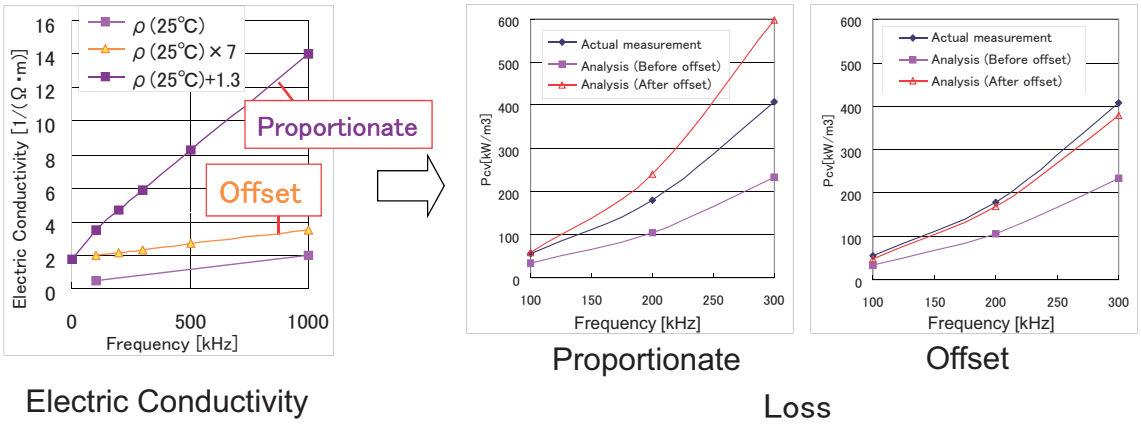
Temperature dependence Frequency dependence

(Created above graphs based on the technical documents of Ferroxcube International Holding B.V.)

It is revealed that the temperature of electric conductivity and frequency dependency is large after some contacts with a core manufacturer!

4. Assumption of Electric Conductivity at high temperature

<Challenge #2> No frequency characteristics other than the one for normal temperature have been detected.



We considered two assumption methods
→We offset the frequency characteristics for normal temperature by the portion of temperature dependence.

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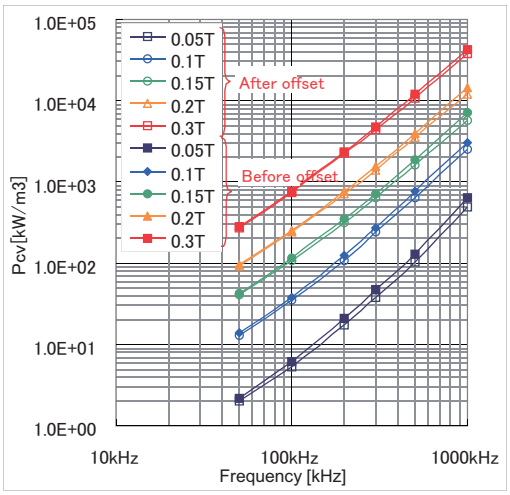
4. Offset of Iron loss characteristic Data

<Challenge #3> At high temperatures and frequencies, eddy current loss in the grain boundary takes up a high proportion of the catalog iron loss characteristics.



We carried out a normal ring core analysis, and created data for the iron loss characteristics while excluding the grain boundary eddy current loss.

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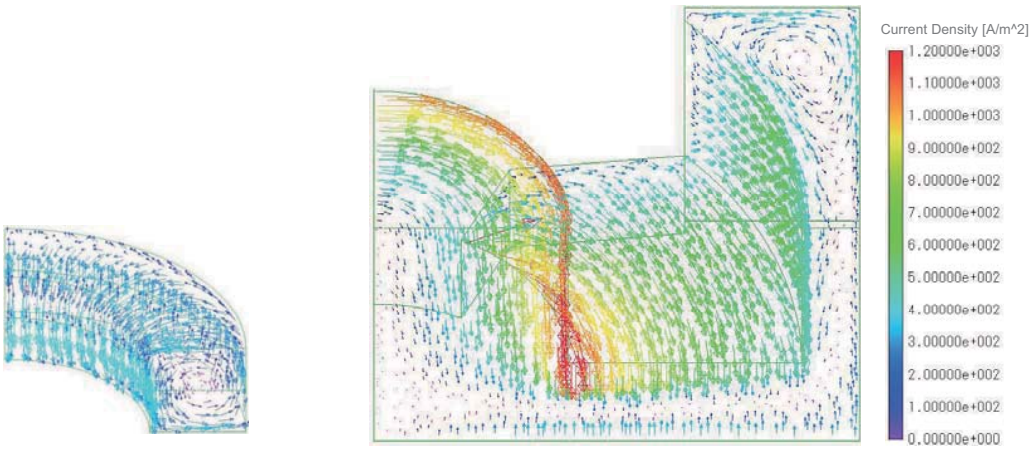
4. Eddy Current Inside the Core

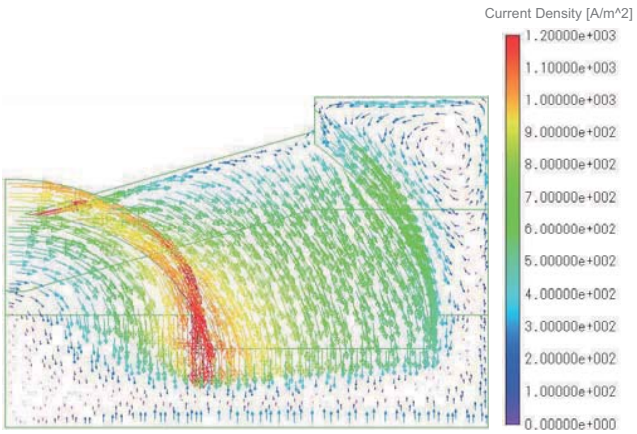


Ring core PM core

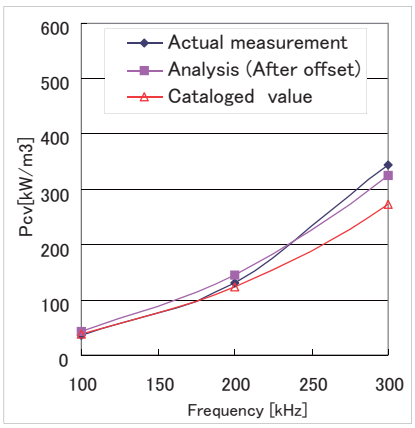
Current Density @0.1T

Differences in the eddy currents are large even with the same magnetic flux densities.

4. Eddy Current Inside the Core (in case of short middle leg)



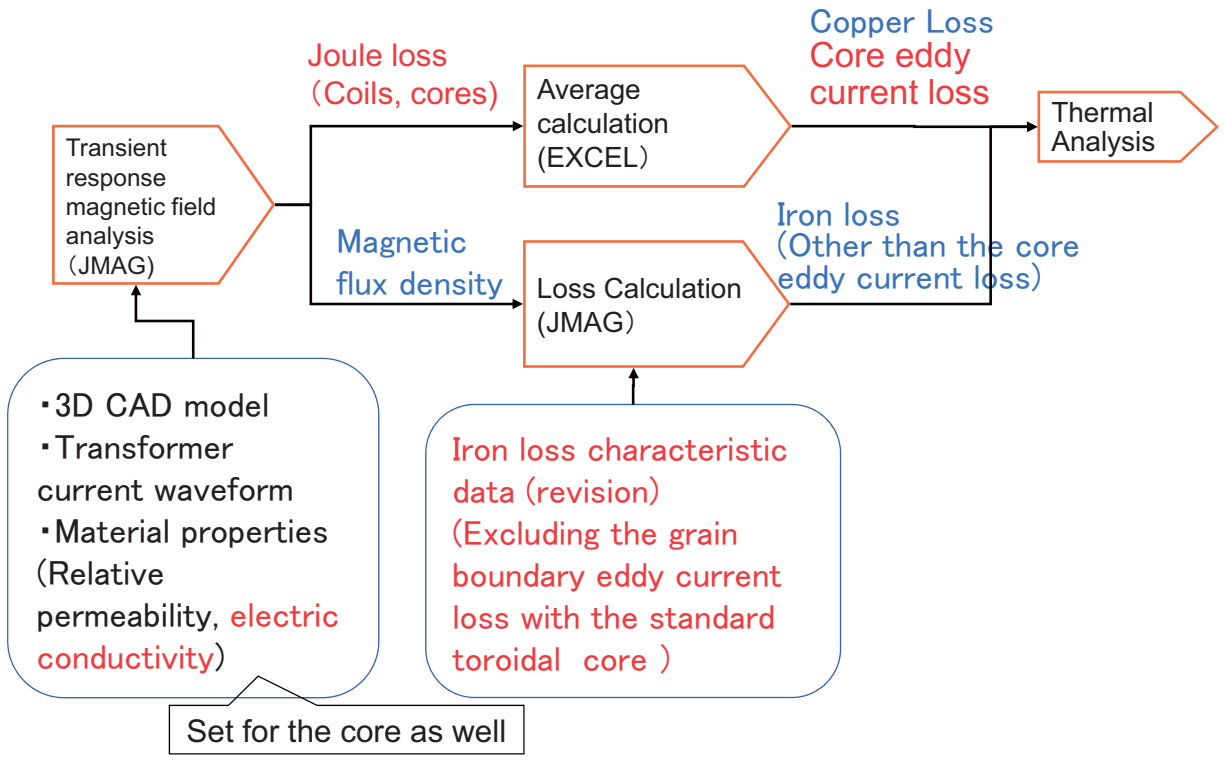
PM core in case of short middle leg @0.1T



Comparison with the iron loss densities

The result matched with the actual value even in the case of a short middle leg

4. Calculation flow of the new method



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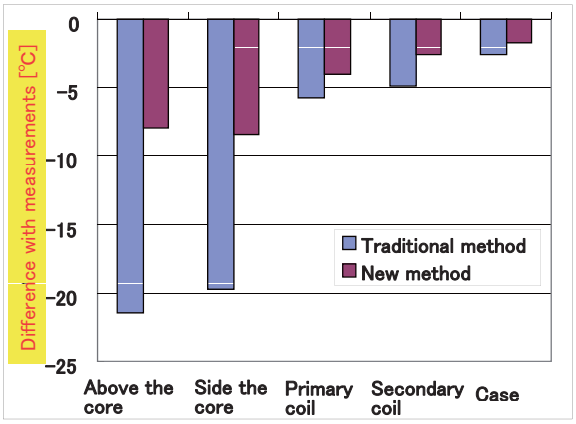
4. Accuracy confirmation with a transformer



Temperature dependence properties of iron loss and electric conductivity

The results matched with an error of less than 8℃ with the new method.

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5. Conclusion

- Understanding coil and transformer loss through magnetic field analysis is indispensible for heat countermeasures that accompany miniaturization of vehicular power sources.

- Under some usage conditions of the vehicle power unit, such as high temperature or high frequency, the electric conductivity of Mn-Zn ferrites increased.

  ⇒ The proportion of eddy current loss over the entire core is large
  So, we developed a method to separately analyze the core Joule loss.

- When we applied analysis to the transformer of a new product, the difference with the actual measurements reduced from 22℃ to 8℃.