

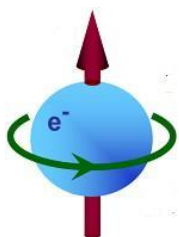
SMAG Visualizer User Manual

Version 3

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By

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ABSTRACT

MagWeb's new **Visualizers** display the magnetic property curves of any magnetic material. You can visualize tens of thousands of magnetic property curves of most grades produced around the world – all with a couple of clicks. With this, you can discover superior grades that best suits your machines. MagWeb offers two visualizers:

- **SMAG Visualizer** - visualizes the magnetic properties of soft magnetic materials.
- **PMAG Visualizer** – visualizes the magnetic properties of hard materials (permanent magnets).

Both visualizers have several powerful interactive tools such as:

- Autocomplete - a pull-down chart lists possible grades as you type
- show/hide any curve
- cursor lists magnetic property data
- zoom and pan any area of the plot
- Visualize button lets you overlay properties of several grades

These visualization tools are available 24/7 from work, home, or anywhere. You can access them from a phone, laptop, tablet, or any computer. You do not need to download, install or license the software. **MagWeb** respects your privacy. It does not leave any cookies nor access to your computer.

This handbook details the **SMAG Visualizer**. It can visualize the magnetic properties of 11 categories of soft magnetic materials (Electrical Steel, Carbon Steel, Stainless Steel, etc). It visualizes both magnetization curves and core loss curves of any grade. The magnetization curves are extrapolated close to saturation. The displayed curves are smooth, monotonic, and are presented at several frequencies and/or temperatures. It can display four types of core loss plots:

- Core Loss Curves $P(B,f)$
- Core Loss + Permeability Curves
- Core Loss Models
- Core Loss Model coefficients

In addition, it can display four types of magnetization plots:

- Normal Magnetization Curves $B(H,f)$
- Ferric Flux Density Curves $J(H,f)$
- Permeability Curves $\mu_r(B,f)$
- Slope Permeability Curves $B'(B,f)$

Subscribers can access magnetic property curves of all grades in all categories of magnetic materials. They can download data or compare any number of grades side by side. Other 'Free' users can access only a limited number of grades. They cannot download any data, nor can compare grades side by side. Further, they cannot access the saturation flux density of any grade or core loss models.

The **MagWeb** visualizers are the result of a multi-decade effort to compile hard-to-find magnetic property data. All this data is curated from **open sources** such as scientific journals, technical reports, manuals, books, websites, federal databases, university records, manufacturer's catalogs, etc. MagWeb believes it curated the data accurately and reliably. The intent is to support you in making informed decisions on magnetic materials, so MagWeb disclaims all warranties. MagWeb is not liable for any damages caused by using its database, whether explicitly or implicitly. The sources and curating methods used to digitize/smooth/model the data are confidential and proprietary. Resale of MagWeb's curated data is not permitted. MagWeb reserves the right to change the data without notice. By entering the password, subscribers agree to abide by MagWeb's General Terms and Conditions for the subscription services.

Users are invited to contribute their magnetic properties of magnetic materials by email to rao@magweb.us

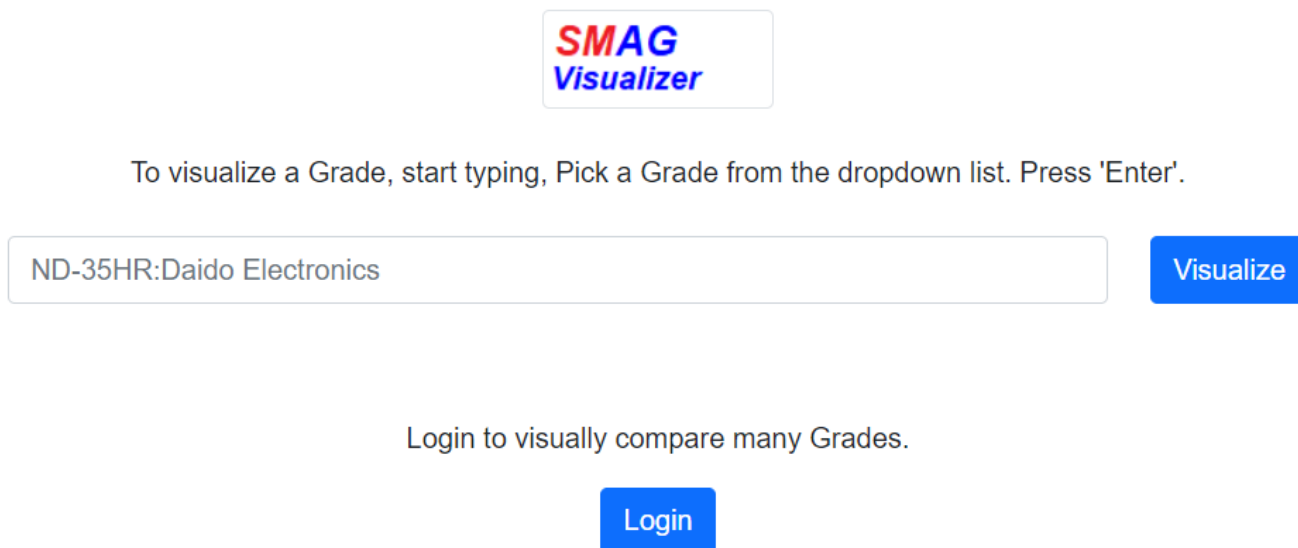
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1. SEARCH PAGE

Fig. 1 shows the Search Page for the **SMAG Visualizer**



To visualize a Grade, start typing, Pick a Grade from the dropdown list. Press 'Enter'.

ND-35HR:Daido Electronics

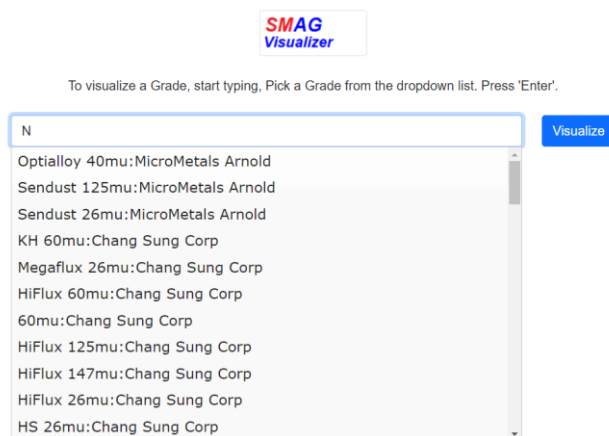
Visualize

Login to visually compare many Grades.

Login

Figure 1. Search Page of the SMAG Visualizer

Start typing a grade. Fig. 2 displays a dropdown list on typing 'N' to visualize Sendust. Pick this grade. Subscribers can pick many grades to compare. Then click 'Visualize'.



SMAG Visualizer

To visualize a Grade, start typing, Pick a Grade from the dropdown list. Press 'Enter'.

N

Optialloy 40mu:MicroMetals Arnold

Sendust 125mu:MicroMetals Arnold

Sendust 26mu:MicroMetals Arnold

KH 60mu:Chang Sung Corp

Megaflux 26mu:Chang Sung Corp

HiFlux 60mu:Chang Sung Corp

60mu:Chang Sung Corp

HiFlux 125mu:Chang Sung Corp

HiFlux 147mu:Chang Sung Corp

HiFlux 26mu:Chang Sung Corp

HS 26mu:Chang Sung Corp

Visualize

Figure 2. Start typing a grade. Pick it from the dropdown list.

In MagWeb, a 'grade name' comprises two parts that are separated by a colon.

- The first part contains the name of the grade that is given by the manufacturer.
- The second part contains the name of its manufacturer.

For example 'M235A-35: Cogent' refers to the M235A-35 grade that is manufactured by Cogent Power. The name of the manufacturer is included because the properties of grades differ subtly with manufacturers.

2. PLOTS PAGE

Fig. 3 shows the Plots page. Its 8 tabs show 8 types of magnetic property curves. 3 tabs relate to core loss (Core Loss Curves, Core Loss Models, CL+ Permeability Curves) while 5 tabs relate to magnetization (Magnetization curves, Saturation Curves, Permeability Curves, Slope Permeability Curves, Reluctivity Curves).



Figure 3. 8 types of magnetic property curves visualized by SMAG.

For example, Fig. 4 displays the core loss curves for the M235-35A:Cogent grade. This grade has 5 core loss curves. The *Legend* (on the top right side of the plot) lists the *name* of all curves. The name in turn lists the temperature. It toggles between 'show' and 'hide'. To show a curve, click its name. To hide it, click it again.

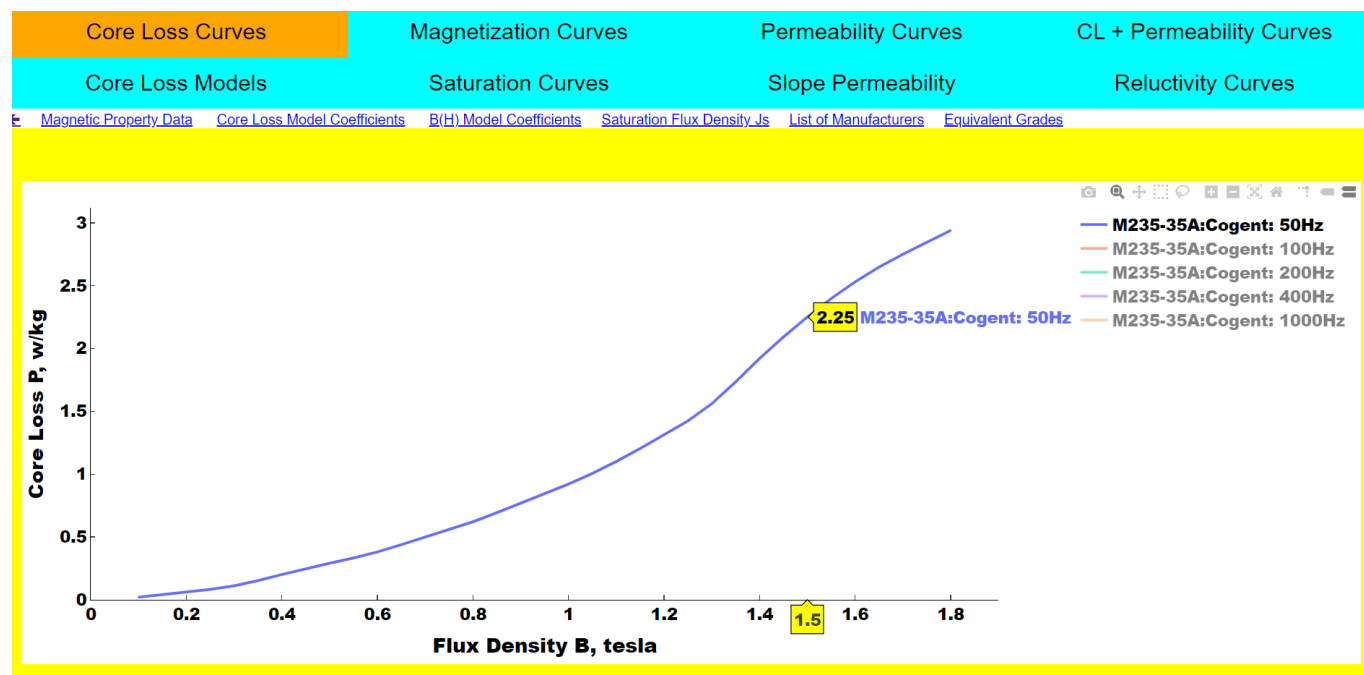


Figure 4. Plots Page displays magnetic properties of the selected grade.

The plots page shows the core loss curves by default. Click different tabs to show different curves (such as Magnetization curves, Permeability Curves, etc.) This plots page also have the following visualization features:

- [DataReader](#)
- Legends
- Visualization tools
- [Subscriber-only](#) links
- Popup Messages

The [DataReader](#) lists the numerical values of a data point. For example, Fig. 4 shows the M235-35A grade from Cogent Power dissipates 2.25 w/kg at 1.5T, 50Hz. The visualization tools (above the legend) help in zooming, panning, box, or lasso selection. The popup messages display any error messages. Appendix A describes these features in greater detail.

3. CORE LOSS CURVES

The core loss curve plots core loss P w/kg vs. flux density B tesla. It is the most important property of magnetic materials. A grade with lower grade loss will dissipate less heat, so the machine will remain cooler. Cooler machines have a longer life. To convert w/kg into mW/cm³, multiply P by density in gm/cm³. For example, for ferrites, multiply P by 4.8 gm/cm³.

The SMAG VISUALIZER can resolve many of your thorny questions such as:

- Which firm offers the best grade (with the lowest core loss)?
- Do thinner grades reduce core loss significantly?
- Do core loss of 'equivalent grades' differ from firm to firm?

3.1. Which manufacturer produces a better M50-470A?

Electrical steels carry 'standard' grade names. For example, one that is 0.5 mm thick, and dissipates 4.7 w/kg at most at 1.5T, 50Hz are called 'M50-470A' grades. Every manufacturer sells his version of this grade. For example, China Steel sells this grade with the '50CS470' label while Baosteel sells it with the 'B50A470' label.

Theoretically, both are supposed to be 'equivalent'. But in fact, they are not. You are faced with the tricky question, which one is better? **SMAG Visualizer** helps you discover which manufacturer produces a better grade.

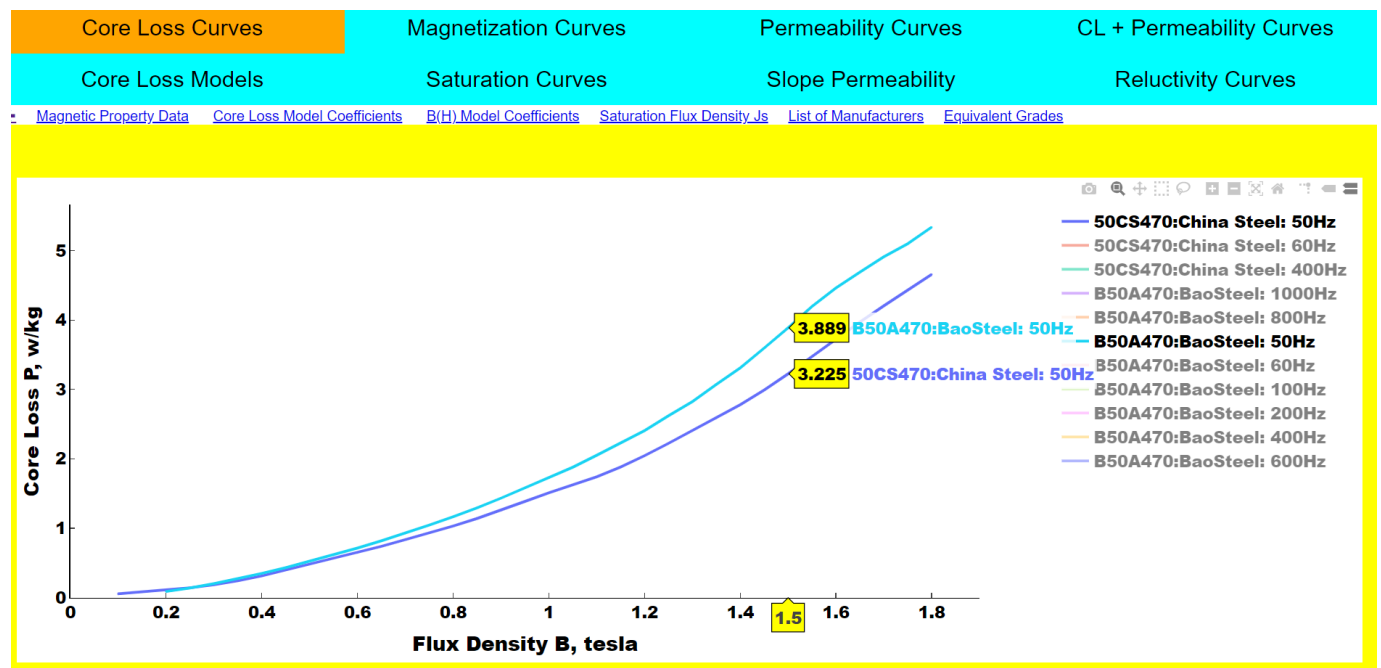


Figure 5. **SMAG Visualizer** helps you discover a manufacturer that produces a better grade.

Fig. 5, produced by SMAG shows that

- China Steel's Grade 50CS470 dissipates **3.225** w/kg
- Bao Steel's Grade B50A470 dissipates 3.889 w/kg.

With SMAG, you discover that China Steel produces a better grade that dissipates 20% less heat. In this way, a subscription to our **SMAG Visualizer** pays itself by helping you design a cooler machine.

3.2. Which ferrite core produces the least core loss?

A transformer-producing customer wants to select the coolest core that operates at 0.15T, 200kHz, 100°C. He has three possible options:

- TPG's TP4A
- TDK's PC44
- Ferroxcube's 3F3

A subscription to **SMAG Visualizer** can resolve this challenge to find which grade offers the lowest core loss. Fig. 6, derived by the VISUALIZE tool, shows the core loss of all three cores overload side by side. It shows that both TPG and TDK core produce the same core loss (108 w/kg). This core loss is 35% less than that for the Ferroxcube's 3F3 (138 w/kg).

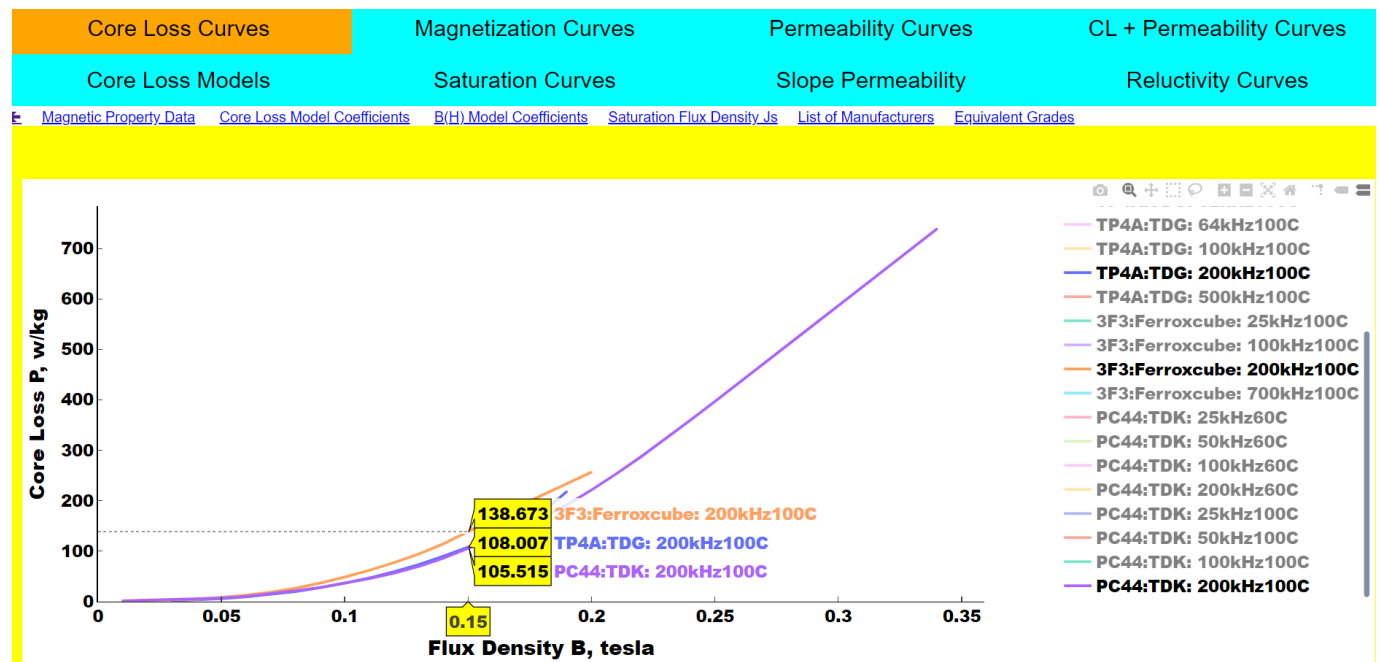


Figure 6. **SMAG Visualizer** helps you discover the best ferrite core

3.3. Are thinner grades worth their lower core loss?

Electric vehicles need traction motors whose electrical steel dissipates less than 15 w/kg at 1T, 400 Hz. To meet this requirement, consider a thin grade vs a thick low-loss grade,

- Grade NO 20 (Cogent, 0.20mm, thin grade)
- Grade 35HX230 (Nippon, 0.35mm, low loss grade).

Fig.7 generated by **SMAG Visualizer** compares core losses from both grades. It reveals that, at 1T 400 Hz, thinner grade produces 30 % lower core loss (12.2 vs 16.165 w/kg).

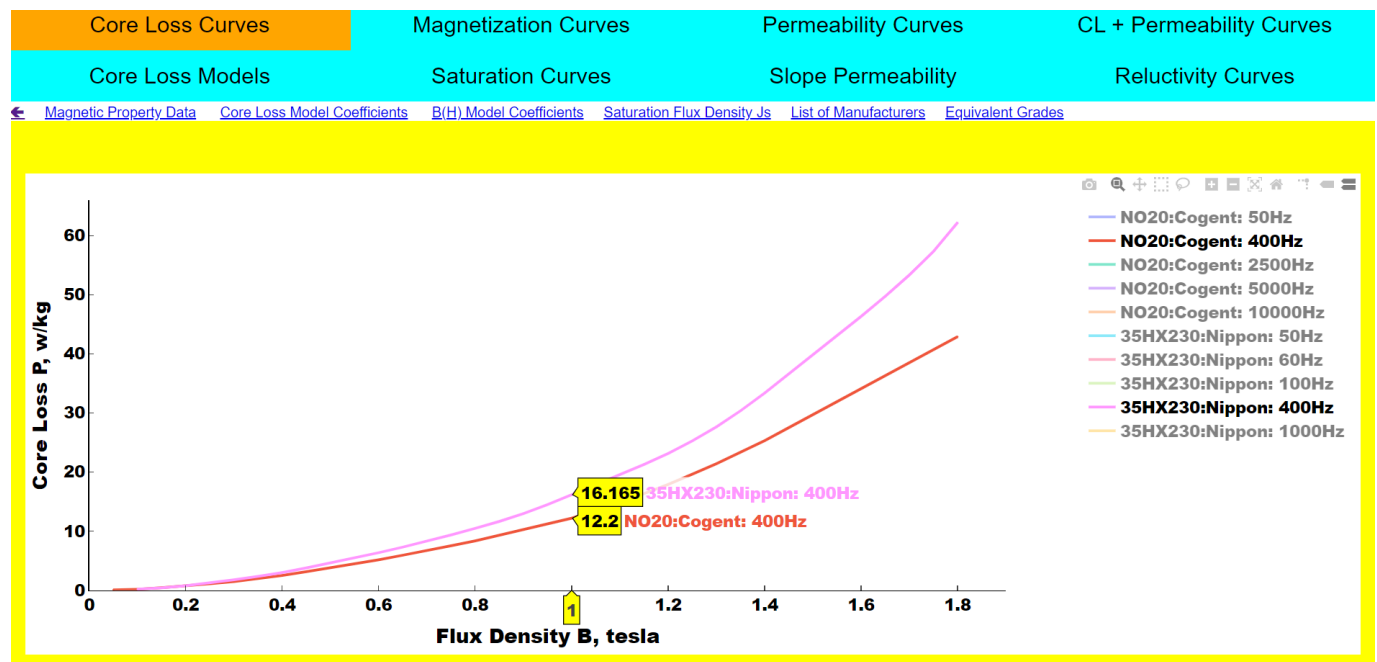


Figure 7. 0.2mm (thin grade) produces 30% less core loss than 0.35mm grade.

4. CORE LOSS MODELS

Core loss models are used by FEM software to compute core loss at any flux density. **SMAG Visualizer** can fit first core loss data with up to 5 popular core loss models shown in Table 2. The last column of Table 2 lists the sequence at which the model coefficients will be outputted by the visualizer.

Table 1. Core Loss Models and Their Coefficients outputted by SMAG Visualizer

Model	In Software:	Model Function $P = P(B, f)$	Coefficients
Steinmetz	MAXWELL	$P = K_h f^n B^m$	K_h, n, m
Steinmetz – Eddy	MagNet, IES, SPEED, OPERA	$P = K_h f^n B^m + K_e (f B)^2$	K_h, K_e, n, m
Bertotti		$P = K_h f B^m + K_e (f B)^2 + K_a (f B)^{1.5}$	K_h, K_e, K_a, m
Maxwell	MAXWELL	$P = K_h f B^2 + K_e (f B)^2 + K_a (f B)^{1.5}$	K_h, K_e, K_a
Bertotti-Flux	FLUX3D	$P = K_h f^n B^m + K_e (f B)^2 + K_a (f B)^{1.5}$	K_h, K_e, K_a, n, m

'Fit error' ε_i is defined as a fraction of deviation between measured and fitted data at an i th point. A *Fit error plot* $\varepsilon(B)$ is a curve that shows how the Fit error ε_i varies with flux density B (from point to point),

$$\varepsilon_i = \frac{P_i - P'_i}{P_i} \quad (0.1)$$

where

P_i = Core Loss measured at i th flux density point B_i

P'_i = Core Loss estimated by a Core Loss Model at the same point

The **SMAG Visualizer** displays both the core loss model as well as the Fit error plot. $\varepsilon(B)$, expressed as a percentage. It displays the core loss on the primary y-axis and error percentage on the secondary y-axis. A core loss model is said to fit the core loss data well if the error is less than 5% in the operating range.

4.1. For electrical steels, is Berttotti Model better than Steinmetz Model?

Fig. 8 shows how Steinmetz and Berttotti models fit the core loss data for Thyssenkrupps grade M400-50A. It shows that, at high flux densities ($B > 1T$), both models fit well (with an error of less than 5%). But at low flux densities ($B < 0.75T$), the Bertotti model fits better, with far less error.

In contrast, the Steinmetz model can produce an error that is as high as 30% or more. As a result, the Bertotti model is recommended to fit such electrical steels.

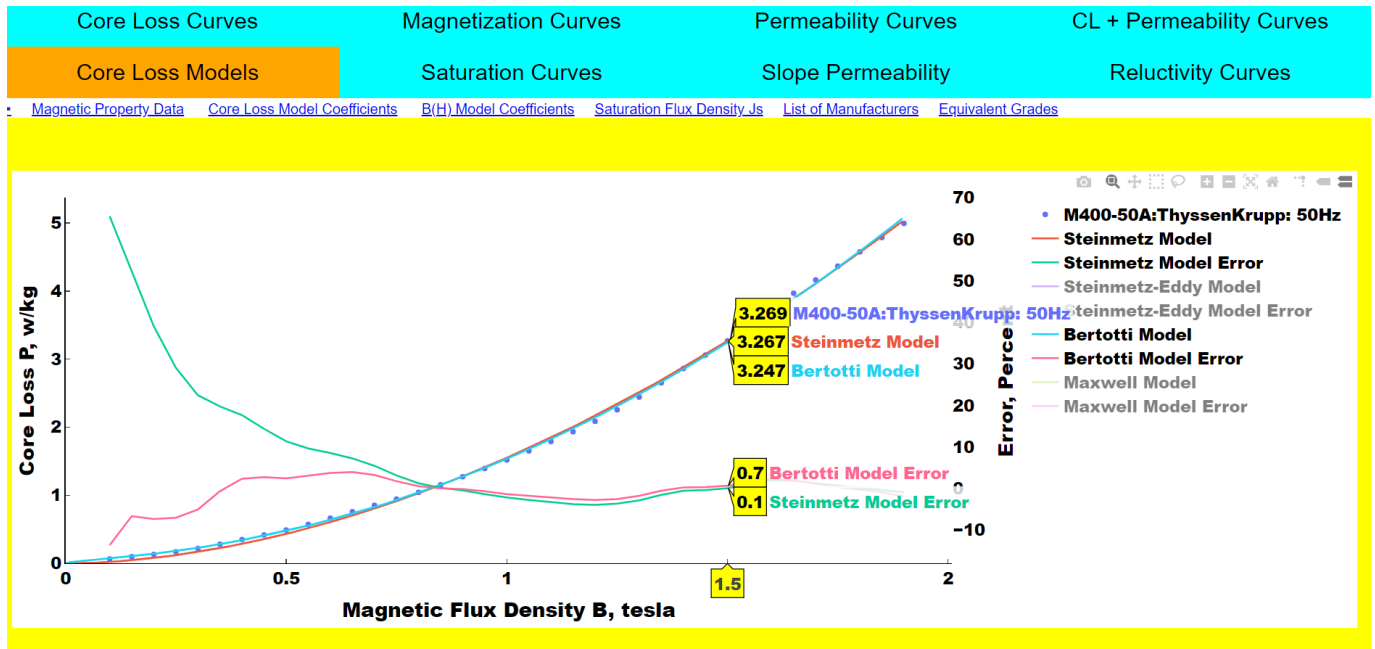
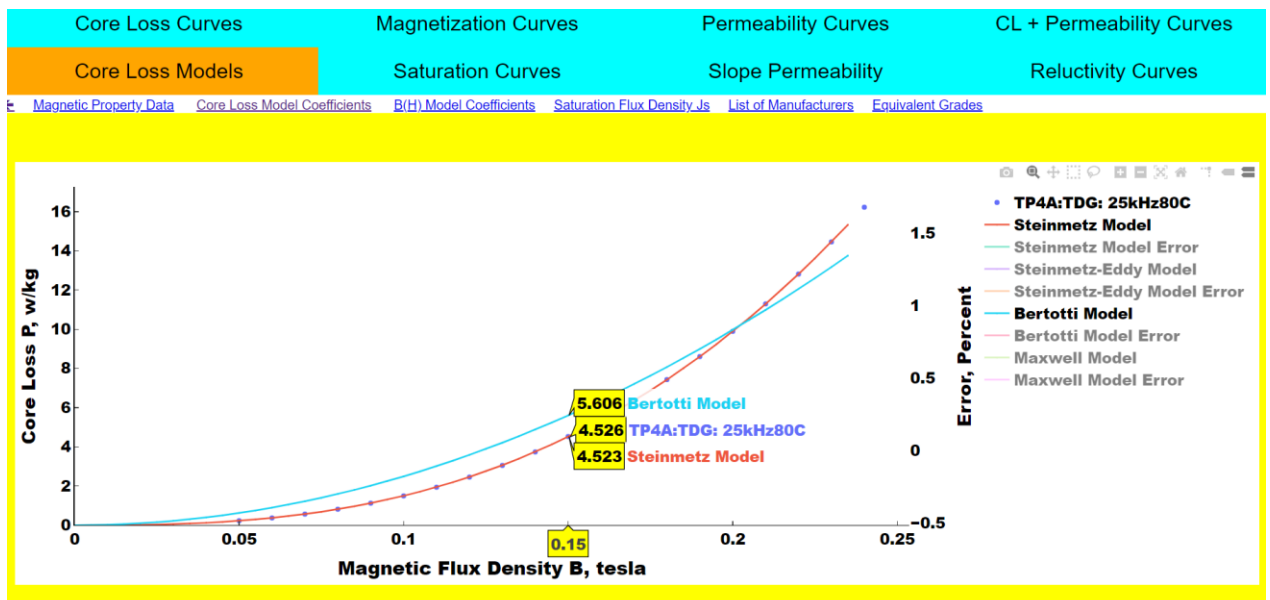


Figure 8. Bertotti model generally fits electrical steels better than the Steinmetz model.

4.2. For ferrites, is Bertotti Model better than Steinmetz Model?

Fig. 9 shows how Steinmetz and Bertotti models fit the core loss data for a ferrite core (Grade TP4A from TPG, at 25 kHz, 80C). It shows that the Steinmetz model fits this core loss data better over the entire flux density range (with error <1%). But in contrast, the Bertotti model fits this data with significantly large error (>30%). As a result, the Steinmetz model is recommended to fit such ferrite cores.



4.3. How does one export coefficients of the core loss models?

The **SMAG Visualizer** will ask for the folder where they have to be downloaded. Select the folder of your choice and click the 'open folder' button. The visualizer will then export an excel file of the model coefficients into this folder. Table 1 illustrates such an excel file generated for the above electrical steel. It lists the coefficients K_h , n , m , etc in the sequence specified in the 'coefficients' column of table 2. For example, for the Steinmetz model, the coefficients K_h, n, m are 0.3678, 0.3681, 1.8349 respectively.

Table 3. Model coefficients exported by SMAG Visualizer as an excel file.

Grade:	M400-50A	Firm:	ThyssenKrupp	Curve:	50Hz
Core Loss Model	Model Coefficients				
Steinmetz	0.367808028	0.368104163	1.834978293	0	
Steinmetz-Eddy	0.196115817	0.000529823	0.022854148	0.540975762	
Bertotti	0.00428915	0.000529823	3.7307E-23	0.540975174	
Maxwell	0.000390098	0.000390098	0.001576111	0	

5. B(H) CURVES

The B(H) curves are used by the machine designers to predict flux densities in the core. The B(H) tab displays the magnetization curve of the user-selected grades. In MagWeb, all B(H) curves are extrapolated beyond the measured data, close to saturation flux density J_s .

5.1. Should one use DC B(H) curve to design a 50Hz machine?

Most motors operate at 50Hz or above. But some well-known manufacturers list only the B(H) curve at 0Hz (known as DC magnetization curve). Some FEM magnetic field software continues to use such DC magnetization curves to design 50 Hz motors. Is this practice of using DC magnetization curves for AC motors justified or misleading? **SMAG Visualizer** can answer such tricky questions.

Fig. 10, generated by the **SMAG Visualizer** software, reveals how B(H) curves vary with frequency. It shows that they differ slightly with frequency. Thus, for accurate simulation, it is preferable to use the B(H) data closest to the operating frequency. Such data is available in the **SMAG Database**.

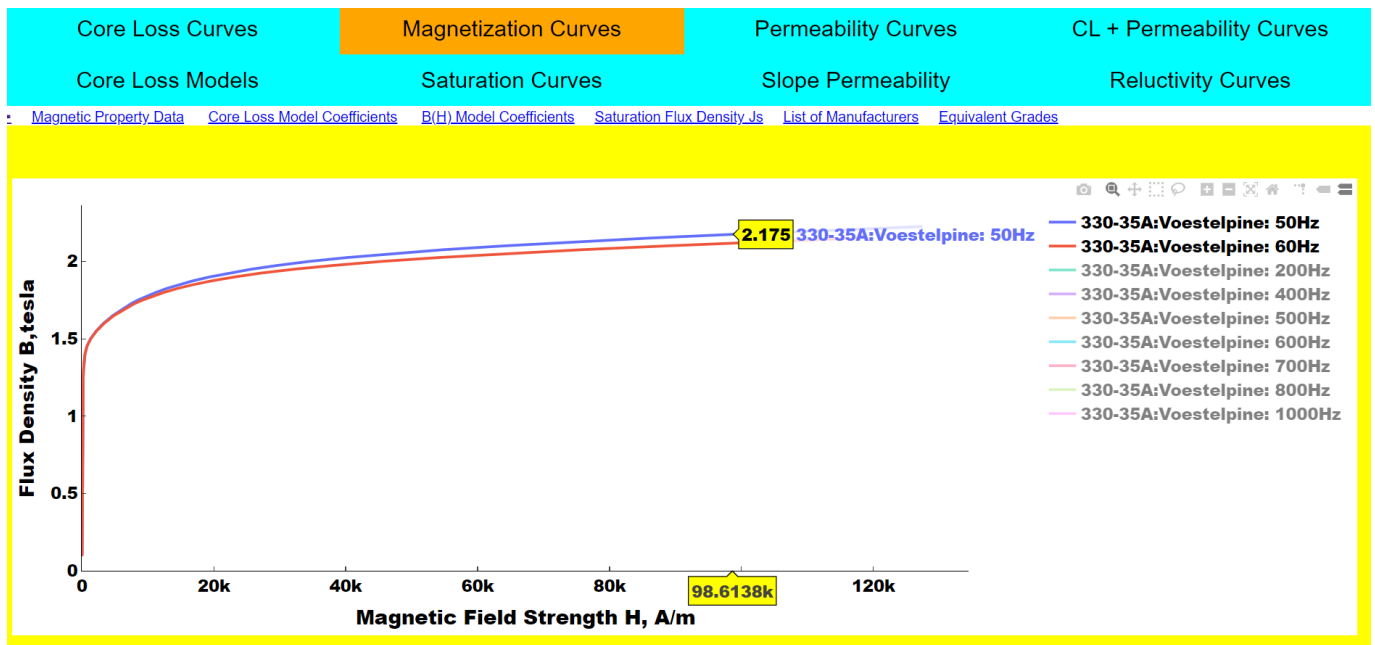


Figure 10. **SMAG Visualizer** shows how 50Hz and 60Hz magnetization curves differ.

6. PERMEABILITY CURVES

The permeability defines the quality of a magnetic material. Grades with higher permeability require less current to deliver a given torque. The permeability tab displays the relative permeability as a function of flux density.

6.1. Which manufacturer offers the grade with the highest Permeability?

Three different firms - AK Steel, Nippon, POSCO – offer diverse grades that are considered equivalent to M50-350. However, Fig. 11, generated by **SMAG Visualizer**, shows that one manufacturer produces a better grade (with higher peak permeability). Specifically, Fig. 11 shows that, at 1T, their relative permeabilities are:

- AK Steel's Grade M-22 19 mil: $\mu_r = 7508$
- Nippon's Grade 50H350: $\mu_r = 6197$
- POSCO's Grade 50PN350: $\mu_r = 5786$

Thus, **SMAG Visualizer** shows that for operation at 1T, AK Steel's Grade is superior from a permeability perspective. But note that, beyond 1.6T, their permeabilities are nearly the same. So for operations beyond 1.6T, there is no perceptible difference between these grades. Thus **SMAG Visualizer** reveals how to select a grade depending on the operating flux density.

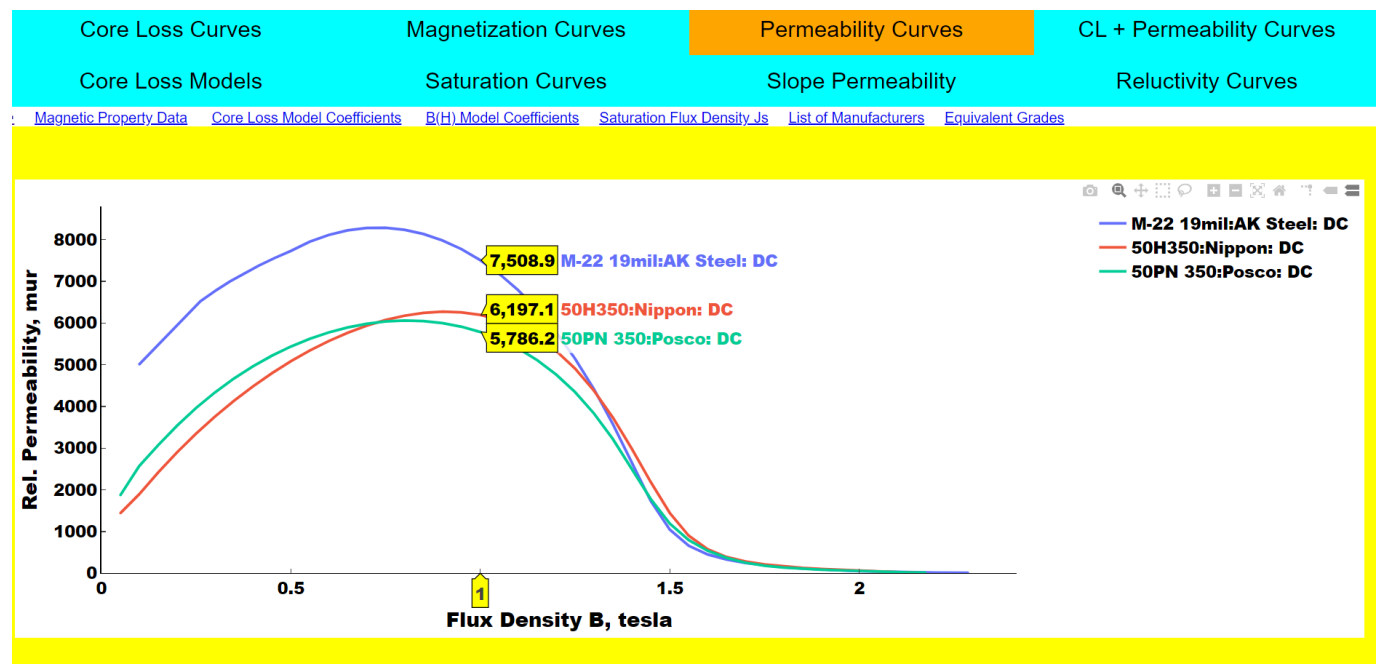


Figure 11. Permeability of equivalent grades differs with manufacturers.

7. BEST GRADE

Magnetic materials differ in their ability to produce heat while carrying alternating fluxes. This ability is shared by both their B(H) curve and core loss curves. A delicate trade exists between both curves and it is always tricky to find which grade produces the highest efficiency. **SMAG Visualizer** helps you better understand this trade.

The **CL + permeability tab** overlays the Core Loss P(B) curves and permeability $\mu(B)$ curves on a common flux density B axis. The primary axis shows Core Loss while the secondary axis shows permeability. We call this a *loss-perm* plot. A loss-perm plot helps you understand the trade between core loss and permeability.

7.1. Which grade is superior?

Consider equivalent grades M-19 (AK Steel) and M270-35A (Cogent Power). Fig. 12 reveals that their permeability differs significantly. At 1.5T, the permeability of AK Steel's M-19 grade is 1565 while that of Cogent's M270-35A grade is 702. Thus from a permeability perspective, AK Steel's M-19 is superior as higher permeability will demand less current, so reduce core loss. But, beyond 1.6T, their permeability is nearly the same, so this superior permeability advantage vanishes. (Note that at 1.5T, AK Steels core loss of 2.56 w/kg is inferior to that of Cogent's 2.47T). Thus, the **SMAG Visualizer** revealed that which grade is superior depends on the operating point of a motor and the trade between permeability and core loss.

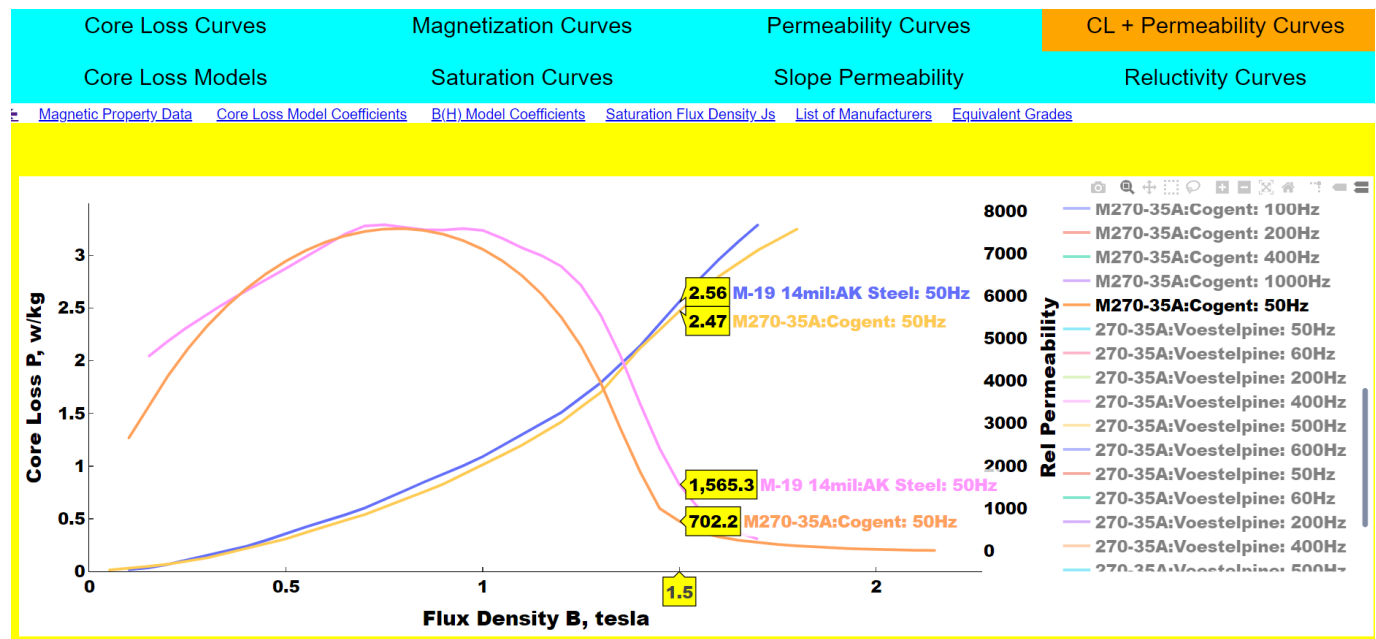


Figure 12. Loss-Perm Plot of equivalent grades

7.2. How to locate Grades that offer high efficiency at a lower cost?

It is well known that the low-loss grades offer higher efficiency, but are expensive. However, in the 1980s, few Japanese publications documented few case histories where less expensive high-loss grades produced higher efficiency¹. How can one find such prized high-loss grades?

Specifically, Fig. 13 displays loss-perm plots of a low-loss Grade M235-35A and a high-loss Grade M330-35A. It shows the high-loss grade increase the permeability (from 612 to 1163) by 100% while increasing the core loss (from 2.25 to 2.94 w/kg) by 30%. An increase in permeability reduces currents required to attain a given torque, so reduces heat. But the quality of such reduction depends on the path length. In large motors, the flux path may be sufficiently long so higher permeability may yield a significant reduction in core loss. On detecting such potential by MagWeb's visualizers, FEM analysis can be used to analyze further such trade which translates to higher efficiency.

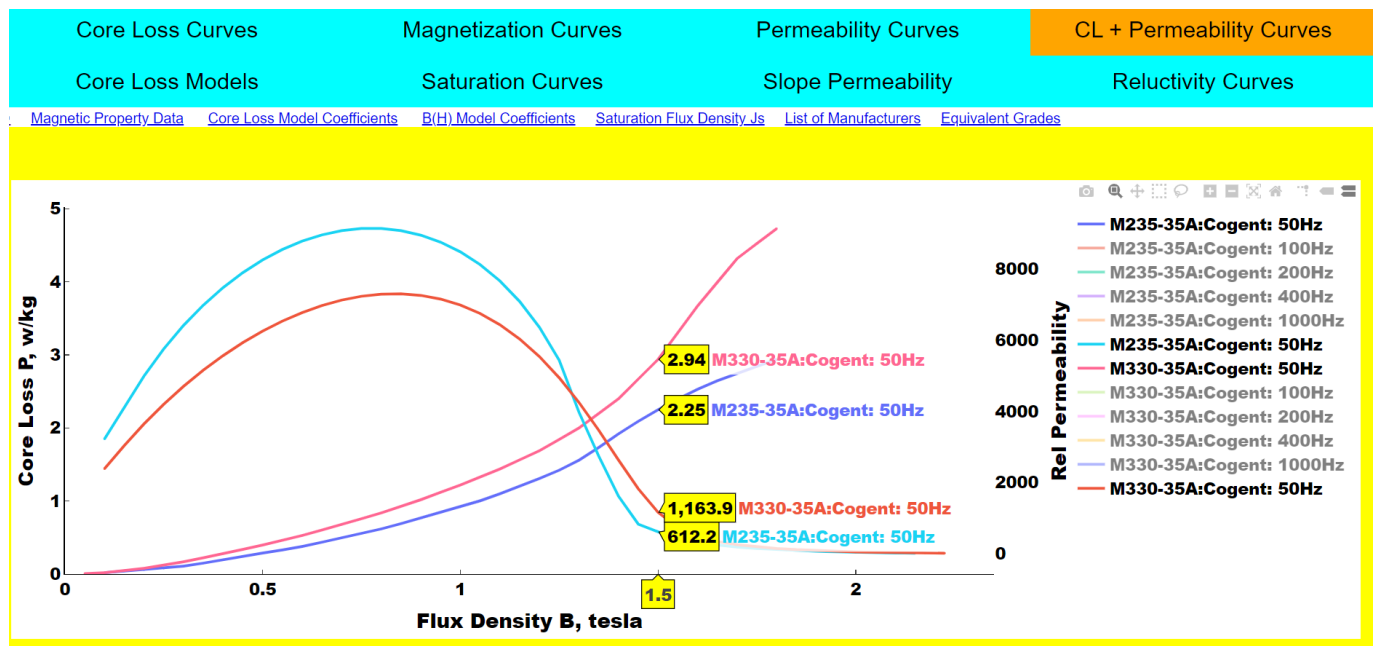


Figure 13. Low-loss grades have lower permeability, so may require more current

¹ Senda, K. et al., "Electrical Steels for Advanced Automobiles, Core Materials for motors, generators and high frequency reactors", *JFE Technical Report*, No. 4, pp. 67-74, Nov. 2004.

8. SATURATION CURVES

The saturation flux density allows you to predict the behavior of a machine in severe duty. The Saturation Curve button displays the ferric flux density $J(H)$ curves of chosen grade.

8.1. Which grade has higher saturation flux density?

Fig. 14 shows that Cogent's M235-35A has higher saturation of ~ 2.011 T compared to equivalent Thyssenkrupps M235-35A which saturates at ~ 1.998T.

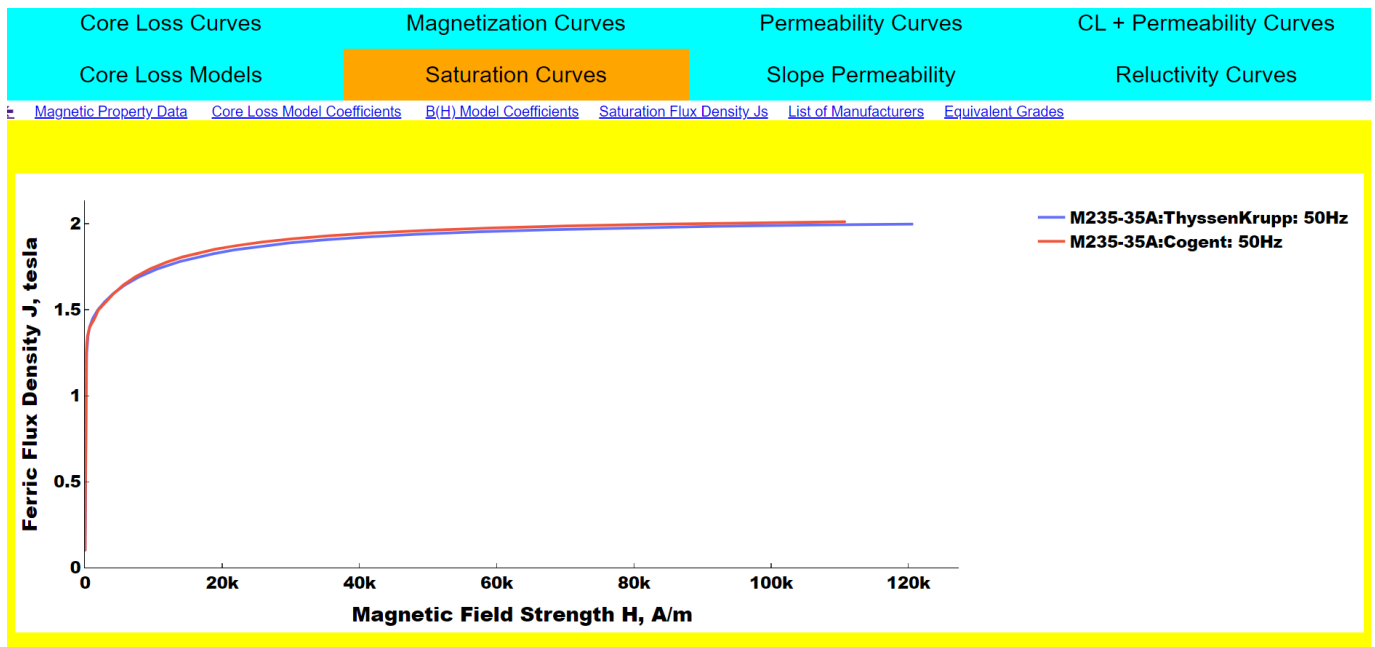


Figure 14. SMAG Visualizer shows Cogent's M235-235A's has higher saturation flux density than Thyssenkrupp.

9. SLOPE PERMEABILITY

The slope permeability B' is $(1/\mu_0) \text{ dB/dH}$. The slope permeability curve helps you to determine if the $B(H)$ data is so rough that it slows the computation. If the slope permeability curve has multiple peaks, the solution may be slow or may not converge. If it has only one peak, then it will not affect the speed of convergence. MagWeb developed proprietary tools to smooth the $B(H)$ data. Version 7 contains such smoothed $B(H)$ data. The use of MagWeb's $B(H)$ data will ensure fast convergence of the solution.

The slope permeability tab displays the Slope Permeability Curves as a function of flux density. You can use it to verify if the $B(H)$ curve will prevent the solution from converging.

9.1. How does one verify if $B(H)$ data is slowing the solution?

Fig 15 compares the slope permeability of two grades from Nippon Steel. It shows that both have a single peak that corresponds to the point of inflection. This indicates that their $B(H)$ data is relatively smooth: it will not slow the solution speed.

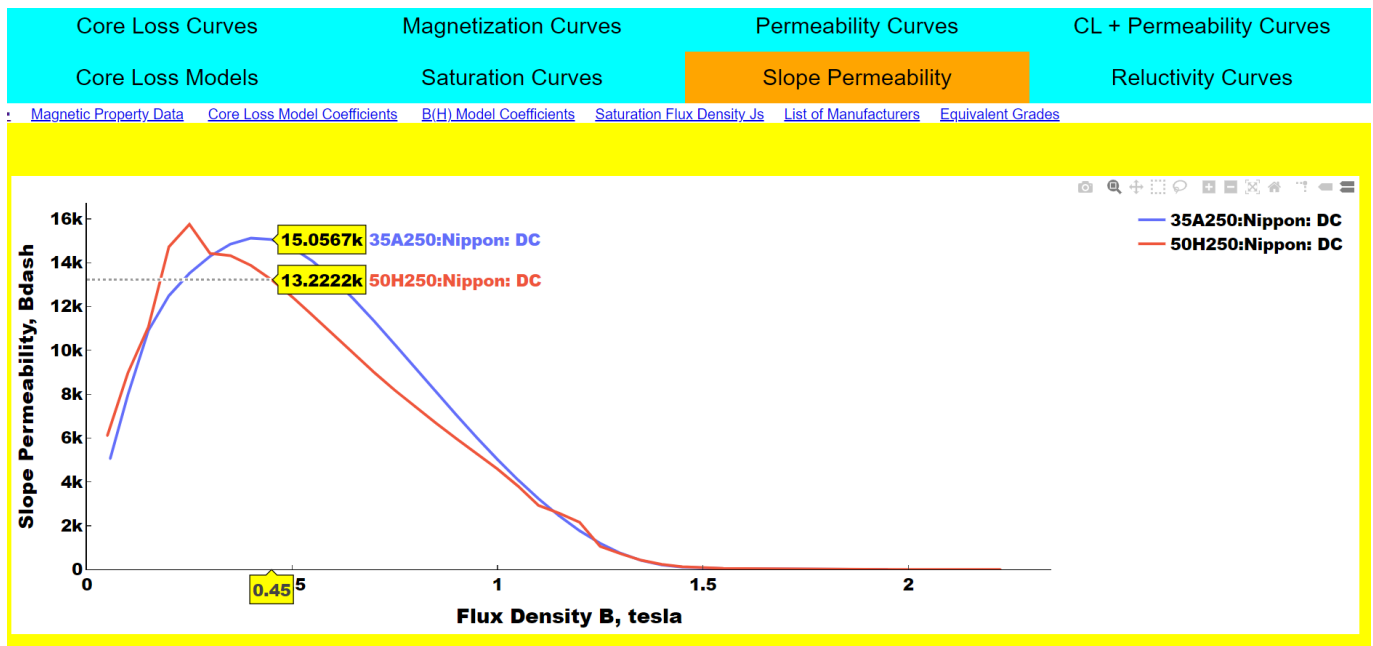


Figure 15. Slope permeability curves of different grades from Nippon.

10. RELUCTIVITY

Reluctivity is defined as the inverse of permeability, $\nu(H) = 1/\mu(H)$. Few legacy firms (and FEM software) use the reluctivity curves to compare which grade can get over fluxed earlier. The Reluctivity tab displays the Reluctivity Curves of the selected grade. For example, Fig 16 shows that both M-19 and M-15 have the same reluctivity curves at 0Hz.

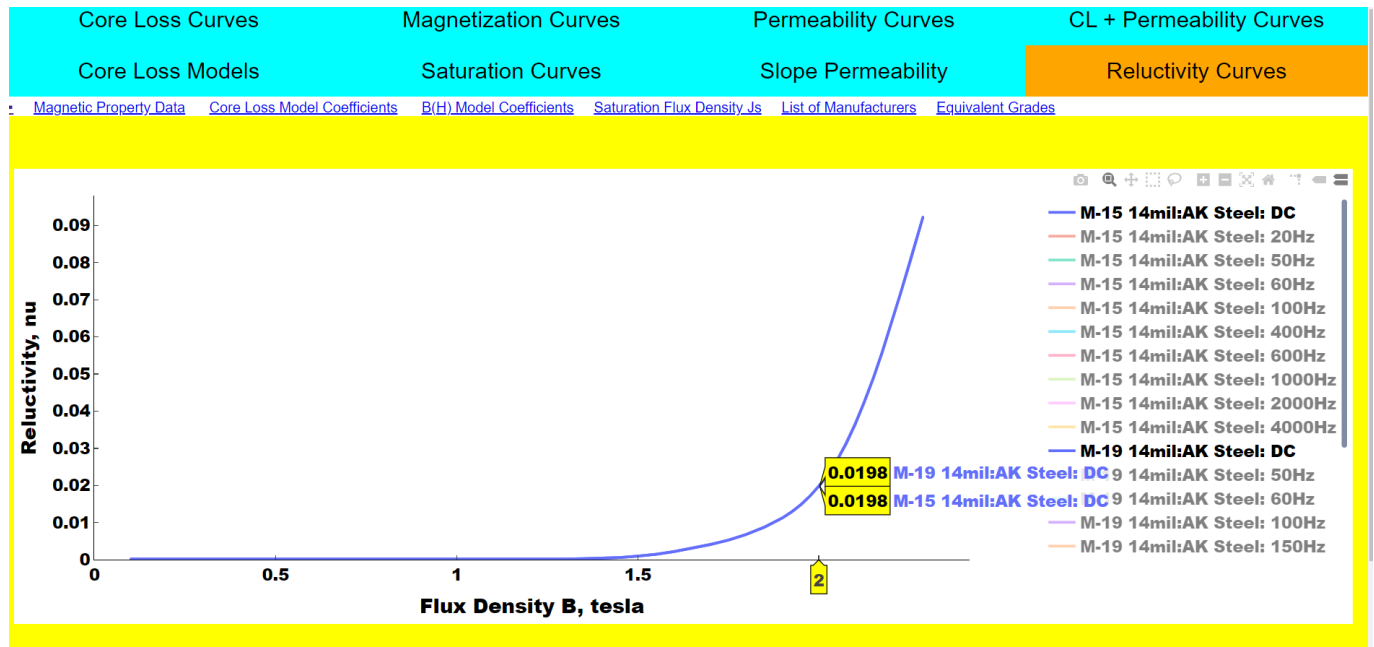


Figure 16. Reluctivity curves of M-15 and M-19 are the same at DC

11. APPENDIX A VISUALIZATION FEATURES

SMAG Visualizer provides several features, e.g.

- Legend
- **DataReader**
- Visualization tools
- Messages
- Links

11.1. Legend

It is located on the top right of the plot. It lists the names of all curves which contains the frequency and temperature information. Click a name to show or hide a curve.

11.2. DataReader

The interactive **DataReader** displays the (x, y) coordinates of a point on all curves. The cursor identifies the position of the point. As you hover the cursor over a curve, it instantaneously updates the coordinates to the cursor point. You can use it to read Core Loss, flux density, permeability, slope permeability, or reluctance, etc. It is also visible in zoom mode.

For example, Fig. 17 shows Core Loss curves for M-15 vs M-19 Grades. The **DataReader** shows that, at 1.1T, M-15 dissipates 1.171 w/kg while M-19 dissipates 1.3 w/kg. It instantaneously shows that M-15 will be 11% cooler.

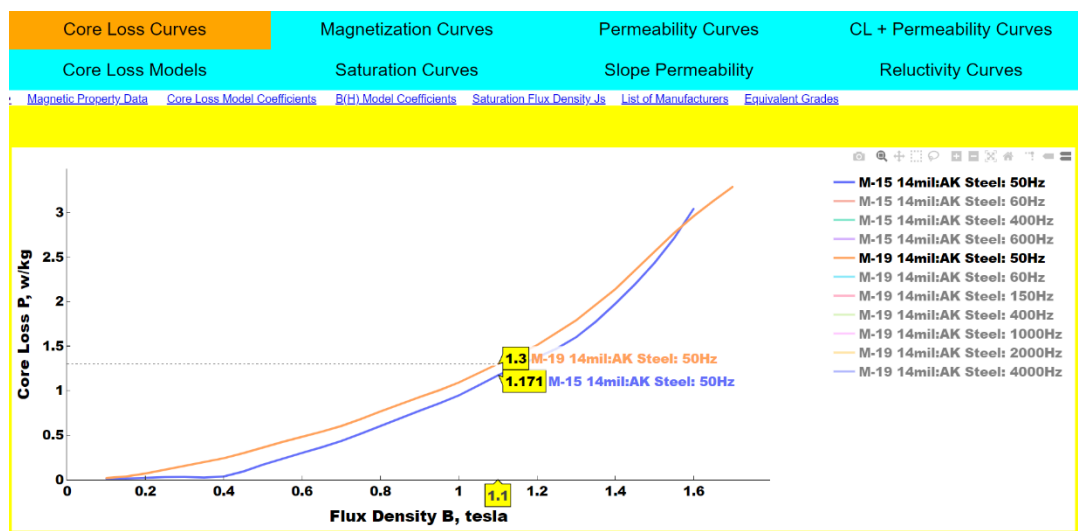


Figure 17. **DataReader** reads the (x,y) coordinates of data points

11.3. Navigation tools

Fig. 18 shows the visualization tools that are available with SMAG and PMAG. It comprises 12 buttons. These buttons allow you to visualize the property curves in a variety of modes. Following is a brief description of these buttons.



Figure 18. Buttons in a Navigation Toolbar. They enhance the data visualization

Save (Camera) Button. Click this button to launch a file save dialog. You can save files in the following formats: png, eps, SVG.



Pan Button: To pan, click this button. Move the mouse over a curve, press the left mouse button, and hold it to pan the figure, dragging it to a new position. When you release it, the data under the point where you clicked will be moved to the point where you released it.



Zoom Button, Click the right mouse button to zoom, dragging it to a new position. **Zoom to Rectangle Mode.** Move your mouse over the chart and press the mouse button. Define a rectangular region by dragging the mouse while holding the button to a new location. When using the left mouse button, the plot view limits will be zoomed to the defined region.

Home Button. Brings the plot back to normal view and position

11.4. Links

Subscribers can access the following additional features, located under the tabs.

- [← return](#) – returns to the Search Page
- [magnetic property data](#) – download magnetic properties (you specify the folder)
- [core loss model coefficients](#) – download model coefficients (you specify the folder)
- [Saturation flux densities \$J_s\$](#) – access the saturation flux density table
- [List of manufacturers](#) – access the list of manufacturers
- [equivalent grades](#) – access the equivalent grades