IEEE International Challenge in Design Methods for Power Electronics

# 2025 PELS MagNet Challenge 2 (MagNet 2025)

*"from Steady State Losses to Transient Hysteresis!"*

Latest Update: https://github.com/minjiechen/magnetchallenge-2

(Updated on January 30th, 2024)

IEEE Power Electronics Society

Princeton University, USA

Dartmouth College, USA

## Competition Sponsors (TBD)

## Awards (MagNet Challenge Total Budget in 2025: $60,000, TBD)

| | | |
|---|---|---|
| Prize for Model Performance<br>1st Place $10,000 | Prize for Model Novelty<br>1st Place $10,000 | Prize for Outstanding Software Engineering<br>$10,000 |
| Prize for Model Performance<br>2nd Place $5,000 | Prize for Model Novelty<br>2nd Place $5,000 | Honorable Mentions<br>$1,000 x multiple |

# 2025 MagNet Challenge 2 Organizing Committee

**For all purposes please contact: pelsmagnet@gmail.com**

## Technical Committee

**Shukai Wang**, Princeton, USA

**Hyukjae Kwon**, Princeton, USA

**Haoran Li**, Princeton, USA

**Minjie Chen**, Princeton, USA

**Charles Sullivan**, Dartmouth, USA

**Thomas Guillod**, Dartmouth, USA

## Judge Committee

**Charles Sullivan**, Dartmouth, USA

**David Perreault**, MIT, USA

**Dragan Maksimovic**, UC Boulder, USA

**Jürgen Biela**, ETH Zurich, Switzerland

**SY Ron Hui**, CUHK, Hong Kong

## Advisory Committee (Pending)

**Gerard Hurley**, National University of Ireland, Ireland

**Maeve Duffy**, National University of Ireland, Ireland

**Brad Lehman**, Northeastern University, USA

**Matt Wilkowski**, Wurth Electronics, USA

**Mike Ranjram**, Arizona State University, USA

**Alex Hanson**, UT Austin, USA

## International Liaison Committee

**Oliver Wallscheid**, Paderborn, Germany — *Europe and Middle East*

**Han Cui**, Tianjin, China — *Asia & Pacific & PELS Publicity Chair*

**Sinan Li**, Sydney, Australia — *Australia, Africa, South America*

# MagNet Challenge 2 Timeline

| | |
|---|---|
| **Feb 1, 2025** | Initial Call for Participation Announcement [Handbook] |
| **March 18, 2025** | APEC Official Announcement |
| **April 1, 2025** | Online Q&A Session |
| **May 1, 2025** | 1-Page Letter of Intent Due with Signature [Attached] |
| **June 1, 2025** | 2-Page Proposal Due for Eligibility Check [TPEL Format] |
| **July 1, 2025** | Notification of Acceptance |
| **August 1, 2025** | Ad Hoc Advisor Feedback |
| **Nov 1, 2025** | Preliminary Submission Due |
| **Dec 24, 2025** | Final Submission Due |

# MagNet Challenge 2 Scope

IEEE PELS MagNet Challenge is a global student competition that aims to seek innovative and efficient uses of measurement data for modeling power magnetics. The competition is open to undergraduate and graduate student teams from recognized engineering programs worldwide. Student teams develop software algorithms to learn from existing training data and compete on unknown testing data. The models trained and developed for different materials will be documented and beneficial for the entire power electronics community.

The competition will develop a family of publicly disclosed software algorithms and tools which learn from existing data and create a model to capture the characteristics of power magnetic materials. Student teams will gain access to data from 10 existing materials to develop the method. The method will be applied to 5 new additional materials as test sets which are similar but also different from the 10 existing materials.

# MagNet Challenge 2 Background

Magnetic components contribute over 30% of the cost and over 30% of the loss in almost all power converters. The performance of magnetic components is an important bottleneck in the development of high-performance power electronics. Circuit simulation tools have greatly accelerated the integrated circuit design process, and numerical field simulation tools have enhanced our understanding of sophisticated component geometries. Despite great progress in simulation tools, the necessary progress in the modeling and design of power magnetics is lagging. Magnetic materials are highly nonlinear, and large variation exists in the magnetic geometries due to the manufacturing process. Although physical theory can explain the phenomena involved in the core loss, it cannot predict it with useful accuracy for practical materials. Existing magnetic material modeling tools are either too simple and thus, not accurate enough or are reliant on experimental measurements that can only be performed after design and fabrication. Models and software tools that can better embrace the data-driven nature of power magnetics modeling are needed.

Designing high-performance magnetics is difficult. It requires long development cycles and extensive engineering expertise. It may take an experienced engineer a few weeks or more to design one version of a reasonably good magnetic component, and usually, many design iterations are needed. The entire power electronics field would greatly benefit from a rapid and precise method for modeling power magnetics.

The standard methods of modeling losses in power magnetics are based on the empirical Steinmetz Equation (SE) proposed in 1890 (more detail is provided in the MagNet Challenge 2025 Technical Motivation section below). Despite several upgrades to the original SE (e.g., iGSE, $i^2$GSE), these curve-fitting methods have limited accuracy. Steinmetz parameters may vary dramatically across the magnetics operating range. As power loss increases, the temperature of magnetic materials also increases, which changes the Steinmetz parameters. There is a pressing need for new design tools and modeling methods for the characterization of winding and core losses that can lead to a better design optimization workflow. Upgrading the Steinmetz equation is a start to revolutionizing the tools and methods used for designing power magnetics.

The MagNet Challenge 1 in 2023 has successfully advanced the state of the art in modeling power magnetics in steady states. It was shown that data-driven, and hybrid data-driven models can greatly advance the modeling and design of power magnetic components. **The 2025 MagNet Challenge 2 will switch the focus to modeling power magnetics in transient.**

# 2025 MagNet Challenge 2 Key Milestones

**Outcome:** A software package that can predict magnetic characteristics for many materials and can quickly be extended and improved to cover new materials when provided with new data.

**April 1st to July 1st – Registration:** Training data was released with the B-H loop information of 10 different ferrite materials under transient operating conditions. Student teams are requested to evaluate the database and submit a letter of intent on May 1st. A two-page proposal describing the key ideas before June 1st, 2025. The committee will evaluate the proposal and notify the eligible teams before July 1st, 2025. **We will attempt to host as many teams as possible.**

**July 1st to Nov 10th – Training:** Each team will develop functions/algorithms in either Python or MATLAB to predict the core losses and B-H loops of many magnetic materials for the 10 materials. A few baseline algorithms will be provided. Teams submit models and results for pre-evaluation.

**Nov 10th to Dec 31st – Submission:** We will release a small amount of new data for 5 new materials. Student teams will adjust their model for the new materials and submit the prediction results for given inputs and codes, together with a 5-page report documenting the key concepts.

**Jan 1st to March 1st – Judging & Evaluation:** The judging committee will evaluate the model's **accuracy**, **size**, **generality**, and **novelty** based on the model’s performance on data that the model has seen (the previously provided data) and extended data that the model has not seen. The results will be announced on March 1st, 2026.

# 2025 MagNet Challenge 2 Motivation

## *"from Steady State Losses to Transient Hysteresis!"*

Preisach model was first suggested in 1935 by Ferenc (Franz) Preisach in the German academic journal Zeitschrift für Physik. It generalized hysteresis as the relationship between the magnetic field and magnetization of a magnetic material as the parallel connection of independent relay hysterons. The relay hysteron is the fundamental building block of the Preisach model. Each hysteron is a two-valued operator $R_{\alpha,\beta}$ which outputs two discrete states. Many relay hysterons are connected in parallel, given weights, and summed together to describe the overall hysteresis behavior of magnetics. It has achieved reasonable success when applied to various engineering domains with hysteresis behaviors.

The Jiles–Atherton model was introduced in 1984 by David Jiles and D. L. Atherton and is one of the most popular models of magnetic hysteresis. Its main advantage is the fact that this model enables connection with physical parameters of the magnetic material, and it enables calculation of minor and major hysteresis loops. There are many different types of implementations for the Jiles-Atherton model with different focuses.

The 2025 MagNet Challenge aims to seek alternatives for the Preisach model and the Jiles-Atherton model with the support of a massive amount of measurement data covering different materials across a wide range of transient operating conditions and temperature. During the data collection process, the materials were intentionally excited with arbitrary waveforms, and they were not operating in steady states. We seek novel and elegant equations or data-driven algorithms to tackle this challenge and advance the entire power electronics society's understanding of magnetic material characteristics in transient.

The challenge has the following two tracks:

(1) **Model performance track:** develop a systematic approach to learn from a large-scale existing database and apply this approach to new data and make accurate predictions.
(2) **Concept novelty track:** any new concepts related to magnetic core loss modeling, including but not limited to fundamental mechanisms, hypothesis, and verifications.

The student teams will be judged based on the model performance and the novelty of the concepts. Student teams are also encouraged to write well-organized and explainable code for evaluation. By submitting the code, the intellectual property is disclosed to the public.

There are intrinsic correlations between the materials behavior in steady-state and in transient. In fact, a model operates well for transient conditions must operate well in steady states. As a result, student teams are encouraged to reuse the data and models made available for the MagNet Challenge 1 in 2023 and leverage the physical and analytical understandings of the models developed for the MagNet Challenge 1 in 2023 for the MagNet Challenge 2 in 2025.

# 2025 MagNet Challenge Technical Rules

*Please refer to https://github.com/minjiechen/magnetchallenge-2 for the latest updates.

The goal of MagNet Challenge 2 is to develop intelligent software tools that can learn and predict magnetic characteristics in transient. For each magnetic material of interest, we are looking for a MATLAB or Python function that takes the following **three inputs**:

1) A pair of $\boldsymbol{B(t)}$ and $\boldsymbol{H(t)}$ waveforms documenting the excitation history from $\boldsymbol{t_0}$ to $\boldsymbol{t_1}$;
2) A future flux density excitation wave $\boldsymbol{B'(t)}$ from $\boldsymbol{t_1}$ to $\boldsymbol{t_2}$;
3) Temperature: $\boldsymbol{T}$.

And produce the following **one output**:

1) The corresponding field strength wave $\boldsymbol{H'(t)}$ from $\boldsymbol{t_1}$ to $\boldsymbol{t_2}$ paired with $\boldsymbol{B'(t)}$.

This function should be packaged as: $H'(t) = function\ (B(t), H(t), B'(t), T)$.

In order to capture the physical behaviors of the magnetic material in transient, the models should be **frequency agnostic**, **time-step agnostic**, and **initial-state agnostic** (always converging after a long time). We encourage using the latest stable version of commonly used MATLAB and Python packages. Analytical methods and machine learning methods are both encouraged.

On **April 1st, 2025**, a large amount of data for 10 materials will be made available at the MagNet Challenge 2 GitHub repository: https://github.com/minjiechen/magnetchallenge-2. The data contains the following information:

1) A large amount of $\boldsymbol{B(t)}$ and $\boldsymbol{H(t)}$ waveforms under arbitrary transient excitations.
2) Temperature: $\boldsymbol{T}$.

The single-cycle volumetric core loss can be estimated by calculating the area of the $B-H$ loops.

The models and datasets made available for the same 10 materials during MagNet Challenge 1 can be downloaded from https://github.com/minjiechen/magnetchallenge. Student teams can use this data to train and test their models in different ways. Other public or private data or datasheets are also allowed for model development, training, and testing. Student teams should properly refer to and clarify the data source in their final report.

On **May 1st, 2025**, a single-page Letter of Intent will be due. Check "Eligibility Information".

On **June 1st, 2025**, a two-page Pre-Proposal will be due. Check "How to Participate".

On **July 1st, 2025**, eligible teams will be announced and notified. Check "How to Participate".

On **August 1st, 2025**, student teams will receive review feedback on their pre-proposal.

On **Nov. 1st, 2025**, Student teams are required to submit a preliminary error evaluation report for each material. A small amount of data for a few NEW materials will be released, together with a wide range of {B(t), H(t), B'(t), T} input for prediction. Student teams can use all information to develop models for these three NEW materials, refine existing models, and use the models to predict results for final submission.

On **Dec. 24th, 2025**, Student teams are asked to submit the **(1) final MATLAB/Python functions** for the 10+5 materials, the **(2) prediction results (in .csv)** for the 5 materials under the specified {B(t), H(t), B'(t), T} conditions, and a **(3) 5-page TPEL style report**. Teams which cannot pass the code review are not eligible to win the prize. The accuracy will be evaluated by the **95th percentile error** of the **core loss** and **B-H loop RMS error** for all test samples. The MATLAB/Python codes should be carefully organized for code review. Please check with the organizing committee about the package dependencies.

*Note: The submission of the models, algorithms, and software package is considered a public disclosure of the key intellectual property. We encourage an open-source culture. However, student teams are allowed to develop their strategy for protecting intellectual property.*

# Awards

All student teams will compete in the two tracks (1) model performance tracking; and (2) model novelty track. The submitted algorithms will be evaluated based on the following criteria:

1) Model performance -> higher accuracy, smaller size, and higher generality.
2) Concept Novelty -> concept novelty of the critical concepts behind the methods.

**Excellence Awards:** awarded to student teams that achieve truly outstanding performance with excellent concepts (Performance 1st, Novelty 2nd). Two awards will be given. First Place: $10,000; Second Place: $5,000.

**Innovation Awards:** awarded to student teams that present truly outstanding concepts with excellent model performance (Novelty 1st, Performance 2nd). Two awards will be given. First Place: $10,000; Second Place: $5,000.

**Honorable Mention Awards:** awarded to student teams that achieve good performance or novelty. Multiple awards will be given: $1,000 per team.

**Software Engineering Awards:** two additional $5,000 prizes for best software engineering.

If possible, we intend to implement the winning models on the MagNet website. Information about the award recipients will be published on the website of the IEEE Power Electronics Society and the MagNet website. The results and technical reports will be recommended to be published in IEEE Transactions on Power Electronics, IEEE Power Electronics Magazine, or other journals.

# Additional Details about the Competition

Budget: PELS TC10 ($35,000) + Industry Sponsorship ($25,000) = Total ($60,000)

# Intellectual Property and Use of Prize Money

By submitting the software codes, models, and algorithms, the students publicly disclose their intellectual property. The PELS MagNet Challenge encourages an open-source culture but does not restrict the use or protection of inventions or other intellectual property produced by participating teams. There are no special licenses or rights required by the sponsors. Teams interested in securing intellectual property protection for their inventions should act before disclosure. The prizes provided to schools are intended to benefit the team members and the design project activities. A LETTER of INTENT (Attachment) is required for the selected student teams to document the team member information and the support from the university.

# External Support and Private Data

Student teams are encouraged to solicit project funding and private data from companies, foundations, utilities, manufacturers, government agencies, or other sources. There is no limitation on the sources of project funding or training data.

# Eligibility Information (contact us if you have special requests)

Eligible schools must have an accredited or similarly officially recognized engineering program; be a college or university with engineering curricula leading to a full first degree or higher; have the support of the school's administration; establish a team of student engineers with an identified faculty advisor; demonstrate the necessary faculty and financial support; and demonstrate a strong commitment to undergraduate education.

**University Eligibility Limit: Cross-university, cross-geographical region collaboration is encouraged for MagNet Challenge 2.** Potential participating schools must submit a Letter of INTENT (attached) by **May 1st, 2025**, to pelsmagnet@gmail.com, for better coordination. The minimum student number is three (3) and the maximum student number is five (5) to qualify for the competition. Each team should consist of between one (1) to two (2) undergraduate students (B.S. or equivalent), between two (2) to three (3) graduate students (M.S./Ph.D. or equivalent), and at least one (1) faculty advisor and optionally one (1) industry mentor. Interdisciplinary and diversified teams are encouraged.

# How to Participate

Participation is on a pre-proposal basis. Interested universities must submit a one-page LETTER of INTENT before **May 1st, 2025**, and a two-page (in TPEL format) proposal before **June 1st, 2025,** to describe the key methodologies before the proposal deadline. **The purpose of the proposal process is NOT to filter student teams but to ensure that all student teams are clear about the competition rules and process and ensure eligibility.** We intend to host as many teams as we can. Schools with qualified proposals will be notified before **July 1st, 2025,** for confirmation. Student teams will then carry out the work and present software demos and results. Instructions for the reports will be posted on the MagNet Challenge 2 GitHub repository. The reports will be judged by a similar expert panel. The student teams will report their results to the organizing committee. Afterward, feedback will be given to the team, and the finalists will be selected. The final submission will be due on **Dec 24th, 2025**. More details will be provided on the MagNet Challenge 2 GitHub repository.

# Judging Panels

The judging panel consists of experts from the IEEE Power Electronics Society (and others to be announced) and representatives from manufacturers, national labs, independent test labs, utilities, and R&D engineers. If any of these members of the judging panel are concerned by a conflict of interest – e.g., that a team of the university they belong to participates in the competition – the person will be replaced by another expert in the field with no conflict of interest by appointment of the organizing committee.

# Judging

Judging score schemes will be set up mainly based on the performance of the produced model (size as evaluated by the kB of the submitted MATLAB/Python codes, accuracy as evaluated by the 95% percentile error of the core loss prediction results, and generality as will be defined by the judgment of the judging panel). The novelty of the proposed concept may include physical insights or algorithmic methodologies, as well as the presentation of the competition results (the 5-page final report). Leveraging open-source software tools and external data is encouraged.

# Administrative Considerations and Limitations

This section describes the limitations placed on the proposal. Compliance is mandatory.

| | |
|---|---|
| Language | The final report must be written in English. Software code submission must be written in Python or MATLAB with clear user guides. |
| Length | The proposal length is limited to 2 pages, the final reports are limited to 5 pages, both in standard IEEE Transaction format (including references).<br>All included model size limit for one material: 10 MB. |
| Authors | The letters of intent and the proposals are to be prepared by the student team with the support of the department and the faculty advisors. |
| Signatures | The letter of intent must be signed by all members of the team. Students must be in student status at the time of the final submission. |
| Letter of Intent | The letter of intent must be signed by a faculty advisor who can help the student teams to coordinate the administrative issue with the university. |
| Key Due Dates | The 1-page letter of intent is due by 11PM US EST on May 1st, 2025.<br>The 2-page proposal is due by 11PM US EST on June 1st, 2025. |
| Webpage | https://github.com/minjiechen/magnetchallenge-2 |
| Email | pelsmagnet@gmail.com |
| Other Emails | minjie@princeton.edu ; sw0123@princeton.edu ; hk1715@princeton.edu |

**ATTACHMENT**

**2025 PELS MAGNET CHALLENGE**

**LETTER OF INTENT**

Submit this page to pelsmagnet@gmail.com by May 1st, 2025, in PDF for registration.

A two-page proposal is due on June 1st to pelsmagnet@gmail.com in PDF for eligibility checking.

NAME OF UNIVERSITY:

CORRESPONDING ADDRESS: ______________________________________________

______________________________ City__________ Country___________ Zip Code ________

MAIN CONTACT EMAIL ADDRESS (.edu): SECOND CONTACT EMAIL ADDRESS (.edu)

__________________________________________ ______________________________________

FACULTY / INDUSTRY MENTOR(S):

Name Affiliation E-Mail Signature

(FACULTY)__________________________________________________________________

(INDUSTRY)_________________________________________________________________

STUDENT TEAM MEMBERS:

Name Major Field of Study Degree Expected Graduation Date Signature

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________

Signature: (Faculty Advisor representing the Participating University)

- I support this team participating in the MagNet Challenge.
- I confirm that I will provide the technical and logistic guidance needed for the research team, including providing the needed funding or computing support by the student team.
- I confirm that I will help with the logistics should the team receive the prize.

Position Title Name Contact Email Date Signature

___________________________________________________________________________