IEEE International Challenge in Design Methods for Power Electronics

2023 PELS-Google -Princeton MagNet Challenge (MagNet 2023)

"It's time to Upgrade the Steinmetz Equation!"

– in 100-year honor of Prof. Charles P. Steinmetz (1865-1923)

Latest Update: https://www.princeton.edu/~minjie/magnet.html

(Updated on Oct 18th, 2023)

IEEE Power Electronics Society

Host: Princeton University, US

Charles Steinmetz (1865-1923)

Magnet developed by Joseph Henry at Princeton University (1832-1846)

Competition Sponsors

Awards (MagNet Challenge Total Budget in 2023: $55,000)

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

2023 MagNet Challenge Organizing Committee

For all purposes please contact: pelsmagnet@gmail.com

MagNet 2023 Chair: Minjie Chen, Princeton, USA

Competition Organizing Committee:

Haoran Li, Princeton, USA

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Alex Hanson, UT Austin, USA

Min Luo, Ekarus Engines, Switzerland

PELS TC10 Steering Committee:

Kevin Hermanns, PE-Systems, Germany

Shirley Pei, University of Bath, UK

Subham Sahoo, Aalborg, Denmark

Miroslav Vasic, UPM, Spain

MagNet Challenge Timeline

Feb 1st, 2023	Initial Call for Participation Announcement
April 7th, 2023	Online Q&A Session and Official Announcement
May 15th ~~1st~~, 2023	1-Page Letter of Intent Due with Signature [Attached]
June 15th ~~1st~~, 2023	2-Page Proposal Due for Eligibility Check [TPEL Format]
July 1st, 2023	Notification of Acceptance [Eligibility Check]
Nov 10th, 2023	Preliminary Submission Due, Finalists Selected
Dec 31st, 2023	Final Submission Due
March 1st, 2024	Winner Announcement and Presentation

*For MagNet 2023, we plan to host 20-30 teams internationally. We will try our best to accommodate as many teams as possible depending on our capability of providing IT support.

MagNet Challenge Scope

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 a few additional materials as test sets which are similar but also different from the 10 existing materials.

MagNet Challenge 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 2023 Technical Motivation section below). Despite several upgrades to the original SE (e.g., iGSE, i^2GSE), 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. Industry representatives are particularly interested in having the ability to design unusually shaped magnetics, instead of using commercial off-the-shelf core shapes and designs. 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.

As a result, we are launching the PELS MagNet Challenge as a platform for students and researchers to compete and showcase their algorithms and new understandings of magnetics.

MagNet 2023 Competition 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 different 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, 2023. The committee will evaluate the proposal and notify the eligible teams before July 1st, 2023. 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 of many magnetic materials based on a large amount of data. 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 a few new materials. Student teams will adjust their model for the new materials, and submit the prediction results for given inputs, 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, 2024.

2023 MagNet Challenge Motivation

"It's time to Upgrade the Steinmetz Equation!"
– in honor of Prof. Charles P. Steinmetz (1865-1923, exactly 100 years ago)

Steinmetz's equation (SE) is an empirical equation used to calculate the power loss (typically referred to as core losses) per unit volume in magnetic materials when subjected to external sinusoidal magnetic flux, proposed by Charles Steinmetz around 1890. A typical SE example is:

$$P_v = k \times f^a \times B^b$$

where P_v is the time average power loss per unit volume in mW/cm^3, f is the frequency in kHz, and B is the peak magnetic flux density in mT; k, a, and b, known as the Steinmetz coefficients or Steinmetz parameters, are generally found empirically from the material's B-H hysteresis curve by curve fitting. In the past decades, the most noticeable upgrade to the Steinmetz Equation is the improved generalized Steinmetz equation, often referred to as iGSE, which calculates losses with any flux waveform using only the parameters needed for the original equation. However, it ignores the fact that the parameters, and therefore the losses, can vary under DC bias conditions and temperature. The iGSE can be expressed as:

$$P_v = \frac{1}{T}\int_0^T k_i \left|\frac{dB}{dt}\right|^a (\Delta B^{b-a})dt,$$

here ΔB is the peak-to-peak flux density in T, and k_i is defined by $k_i = \frac{k}{(2\pi)^{a-1}\int_0^{2\pi}|cos\theta|^a 2^{b-a} d\theta}$. Here, a, b, and k are the same coefficients used in the original Steinmetz equation. The iGSE is still widely used in academia and industry because most other models require parameters that are not usually given by manufacturers and that engineers are not likely to measure.

The 2023 MagNet Challenge aims to upgrade the Steinmetz equation with the support of a massive amount of measurement data covering different materials across a wide range of frequencies, waveform shapes, temperatures, and dc-bias. 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 core characteristics, especially core loss. 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.

2023 MagNet Challenge Technical Rules

*Please refer to http://mag-net.princeton.edu under MagNet Challenge for the latest updates.

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

1) Single-cycle flux density waveform in 1024-step floating point: B(t) (unit: Tesla).
2) Operation frequency in floating point: F (unit: Hz).
3) Temperature in floating point: T (unit: degrees Celsius).

*Note: In MagNet 2023, we fix dc-bias as 0 to ensure the highest data quality. Students are encouraged to consider dc-bias information which may be included in future competitions.

And produce the following **one output**:

1) An average volumetric core loss estimation in floating point: Pv (unit: W/m^3).

This function should be packaged as: $P_v = function\ (waveform, frequency, temperature)$.

The MATLAB or Python function can be freely implemented but please ensure the highest system compatibility with the latest software versions and related packages used (by default we use MATLAB 2022b, and Python 3.9). We encourage using commonly used, open-source MATLAB and Python packages. Analytical methods and machine learning methods are both encouraged.

On **April 1st, 2023**, a large amount of data for 10 materials will be made available at the MagNet website: http://mag-net.princeton.edu. The data contains the following information:

1) Single-cycle flux density waveform (B(t)) in 1024-step (unit: Tesla).
2) Single-cycle magnetic field strength waveform (H(t)) in 1024-step (unit: (A/m)):
3) Sampling time in floating point (unit: second), which can be used to calculate frequency.
4) The temperature in the floating point (unit: degrees Celsius).

The single-cycle volumetric core loss can be estimated by calculating the area of the B-H loop. Student teams may choose to down sample the 1024-step to trade accuracy for model size.

Datasets for 10 materials can be downloaded from http://mag-net.princeton.edu under MagNet Download. 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. Student teams should clarify what data are used in their final repost.

On **May 15th, 2023**, a single-page Letter of Intent will be due. Check “Eligibility Information”.

On **June 15th, 2023**, a two-page Pre-Proposal will be due. Check “How to Participate”.

On **July 1st, 2023**, eligible teams will be announced. Check “How to Participate”.

On **Nov. 10th, 2023**, 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), f, 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. 31st, 2023**, Student teams are asked to submit the **(1) final MATLAB/Python functions** for the 10+3 materials, the **(2) prediction results (in .csv)** for the 3 materials under the specified {B(t), f, 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 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 Award an additional $5,000 prize 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 ($20,000) = Total ($55,000)

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 eligibility 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: Each university's geographical campus is limited to support ONE student team (possibly extend to TWO). Cross-university collaboration is encouraged. Potential participating schools must submit a Letter of INTENT (attached) by **May 1st, 2023**, 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, 2023**, and a two-page (in TPEL format) proposal before **June 15th, 2023,** 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, 2023,** 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 website. 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 31st, 2023**. More details will be provided on the MagNet website.

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). 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 from 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, 2023. The 2-page proposal is due by 11PM US EST on June 1st, 2023.
Website	http://mag-net.princeton.edu
Email	pelsmagnet@gmail.com
Other Emails	minjie@princeton.edu ; haoranli@princeton.edu

ATTACHMENT

2023 PELS MAGNET CHALLENGE

LETTER OF INTENT

Submit this page to pelsmagnet@gmail.com by May 15th, 2023, 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

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Signature: (Faculty Advisor representing the Participating University)

- I support this team participating in the MagNet Challenge and will offer needed help.
- I confirm that this is the ONLY team from my university participating in the challenge and will coordinate with my colleague if there is a conflict registration.
- I confirm that the university will help with the logistics should the team receives the prize.

Position Title Name Contact Email Date Signature

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