AC 2011-76: WEB-BASED MAGNETIC DESIGN

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Web-Based Magnetic Design

Abstract

Magnetic components such as inductors and transformers are undoubtedly a critical component in many electrical engineering systems. Yet, there seems to be a lack of coverage of magnetic design topics in undergraduate electrical engineering curriculum around the world. In fact, only a few universities in the US offer a course where undergraduate students get the opportunity to design and build their own inductor or transformer. Hence, it is not surprising to observe that many electrical engineering students graduate without having the basic knowledge, skill or experience on designing and building even a very simple inductor. This paper presents a web-based magnetic design which was recently put together to serve as a learning tool for students to understand the basic design procedures of designing and building commonly used magnetic components such as transformers, gapped inductors, and toroidal inductors. The website may also be used as a teaching aid for faculty who teach a course in magnetic design. The website further allows users the flexibility to have new information added into the website such as new magnetic core configurations and core material data. The paper explains and describes the operation of the web-based magnetic design along with examples of user's interface for entering the necessary data for the design.

Introduction

Magnetic components have been used extensively through the practice of electrical engineering, yet there exist few courses in the U.S. that deal in any comprehensive manner with the subject of magnetic design[1]. One example of a widely used magnetic component in engineering systems is inductor. Despite their thread of use in engineering applications, inductors are commonly covered in undergraduate electrical engineering curriculum with emphasis in their functionalities in circuits. Hence, electrical engineering students typically possess the skill to determine the proper rating and size of inductor given a particular circuit application. However, the expectation from industry for electrical engineering graduates related to skills and knowledge on inductors or magnetic in general has increased recently to include the design aspect of magnetic components. This is due mostly to the emergence of modern applications in power systems as well as advances in power electronics for energy efficiency and renewable energy applications. Electrical engineering graduates going into power semiconductor industries for example are now expected to know some basic design skill on laminated iron-core inductors as they are widely used in the power electronics industry[2]. The importance of introducing a more comprehensive coverage on applied magnetic is further stressed by the growing list of new permanent magnet materials that promise to open up new applications that require extremely high coercivity. Examples are rare-earth alloys, amorphous metallic alloys which have now been added to the growing list of commercial magnetic materials that are available to design engineers.

The issue on lack of "magneticians" has in fact long been recognized by industrial group[3] and has encouraged several universities in the US to introduce more applied magnetic design into their undergraduate curricula[4]. In attempt to address this issue, the Education Committee of the IEEE Magnetics Society has debated the question of whether to ask for a minimum competency in magnetic design for accreditation[4], but fell short of actually taking such a step.

At Cal Poly State University in San Luis Obispo we have taken the position that magnetic design is a critical design skill set to electrical engineering that it has had for a long time a technical elective course in magnetic design[5]. The course is numbered EE 433 entitled “Introduction to Magnetic Design” whose description is as follows[6].

> Design of magnetic components. Fundamentals of magnetics, magnetic cores, design of power transformer, three-phase transformer, dc inductor, ac inductors, dc-dc converter transformer design, actuators. Use of commercially available software. 3 lectures, 1 laboratory. Prerequisite: EE 255&295 or consent of instructor.

In 2008, the course underwent a major revision to cover more applied topics and to introduce new laboratory experiments where students conduct hands-on and practical designs on inductors and transformers. In this paper, a web-based magnetic design that will serve as a design tool to aid students taking the course in understanding and performing step-by-step procedures on magnetic design will be presented. Although geared more toward a learning tool for undergraduate electrical engineering students, the new web-based design could also provide a useful tool and reference for any practicing engineers who want to learn the basics of designing inductors and transformers.

Web-based Interface

The magnetic design course as it is currently presented first reviews basics of magnetics, magnetic circuits, and several power supply topologies before going into the design aspects of magnetic components such as transformers and inductors. There are currently several methods of magnetic designs ranging from finite element method to more empirical methods. For the course, the design procedures closely follow those presented by McLyman[7], namely the Area Product (Ap) and Core Geometry (Kg) methods. The web-based design therefore contains these methods as applied to magnetic components. More specifically, users of the web-based magnetic design have the options of choosing magnetic design procedures for three types of components: power transformer, gapped inductor, and toroidal inductor. Once a component is selected, users then choose either the Ap or Kg method as shown in Figure 1.

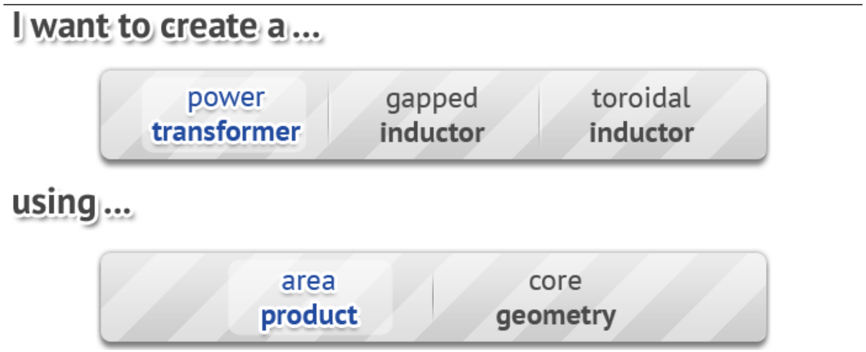
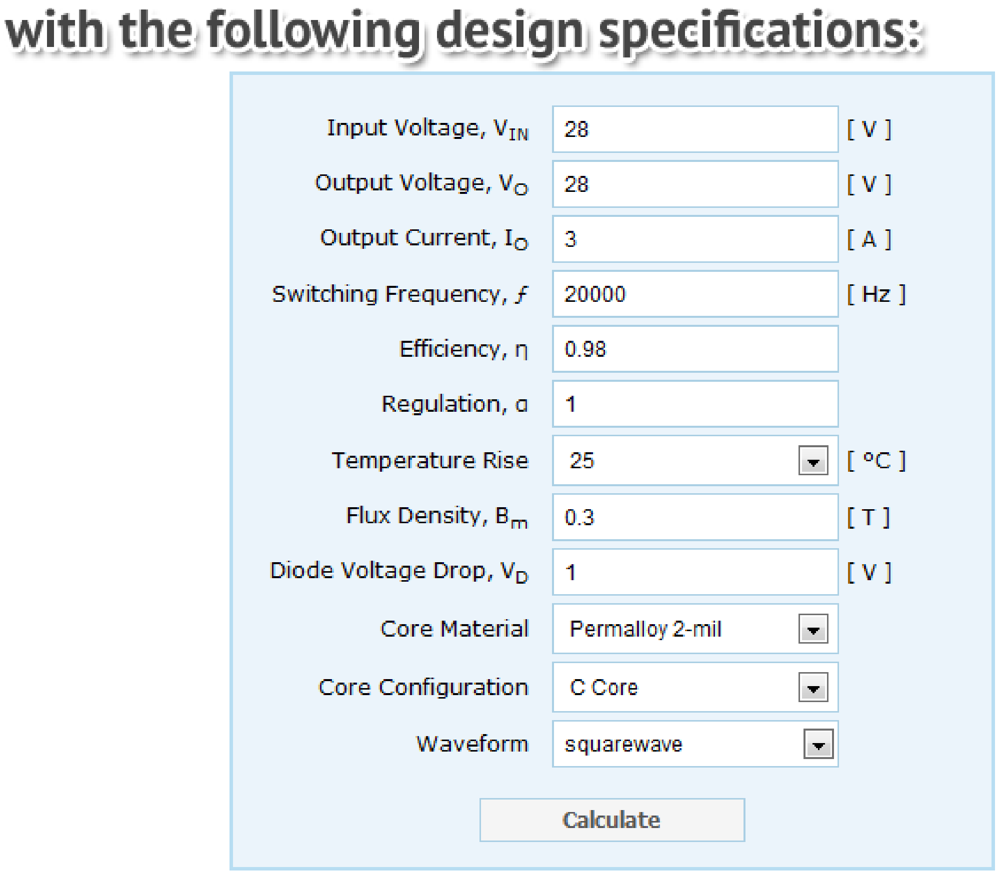


Figure 1. Start-up page

Once a design method is selected, several input text boxes appear for which users have to enter data pertaining to design specifications of the chosen magnetic component. An example is provided in Figure 3 showing the default values.



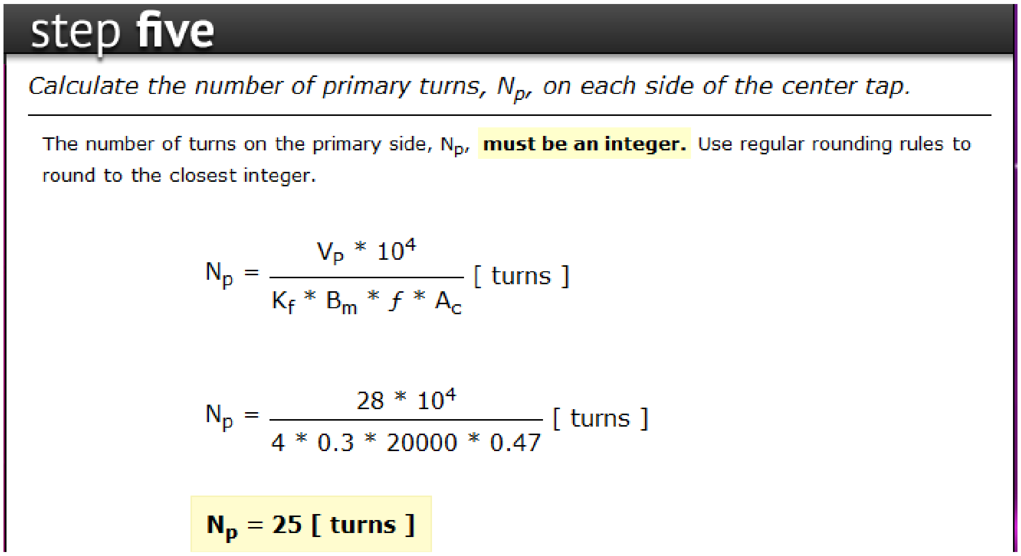
with the following design specifications:

Input Voltage, V_{IN}	28	[V]
Output Voltage, V_O	28	[V]
Output Current, I_O	3	[A]
Switching Frequency, f	20000	[Hz]
Efficiency, η	0.98	
Regulation, α	1	
Temperature Rise	25	[°C]
Flux Density, B_m	0.3	[T]
Diode Voltage Drop, V_D	1	[V]
Core Material	Permalloy 2-mil	
Core Configuration	C Core	
Waveform	squarewave	

Figure 2. User's required input data for design specifications

One important feature of the web-based design tool is that the core material selection used in design calculation (Figure 2 shows "Permalloy 2-mil" core) may be added by the administrator of the web-based magnetic design as data for other core materials are made available by magnetic core companies. The same applies to the type of core configuration (Figure 2 displays "C Core").

Upon completing the design specification section, users can then click the "Calculate" button and the program will perform design calculations whose results are presented as step-by-step procedures showing the equations and assumptions used to help the users understand how result from each step is being calculated. For transformer design, the program displays 22 design steps while inductor design will yield 18 design steps. The transformer design has more design steps since its design involves calculations for both primary and secondary sides. These design steps include basic design calculations such as component's real output power in Watts, component's apparent output power in volt-amps (VA), Area Product or Core Geometry, core selection, number of turns, to name a few. Figure 3 depicts step 5 showing the equation used and how result is being calculated from the given data in the design specification section.



step five

Calculate the number of primary turns, N_p, on each side of the center tap.

The number of turns on the primary side, N_p, **must be an integer.** Use regular rounding rules to round to the closest integer.

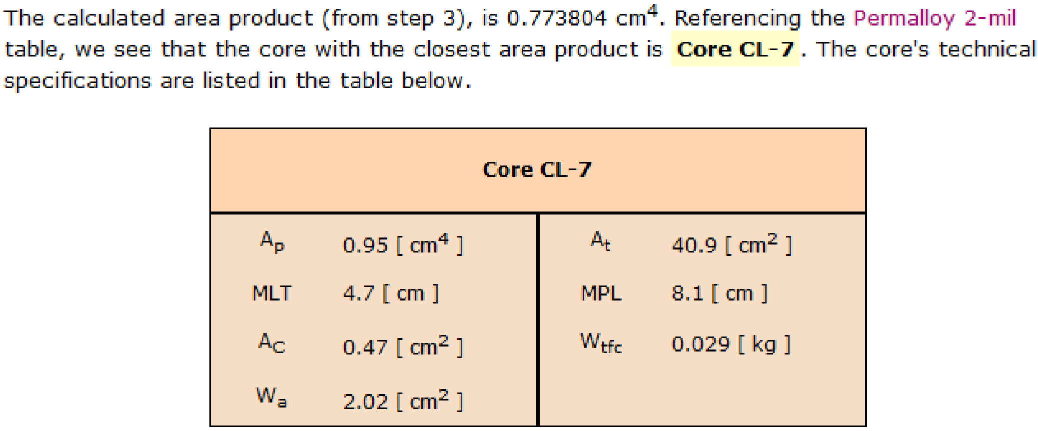
$$N_p = \frac{V_p * 10^4}{K_f * B_m * f * A_c} \text{ [turns]}$$

$$N_p = \frac{28 * 10^4}{4 * 0.3 * 20000 * 0.47} \text{ [turns]}$$

N_p = 25 [turns]

Figure 3. Step 5 for calculation of the number of primary turns in a transformer

Figure 4 illustrates another important feature of the web-based magnetic design. In particular, based on the inputted data for the design specification, the program automatically searches for the closest commercially available core that meets the technical specifications from the database of core materials.

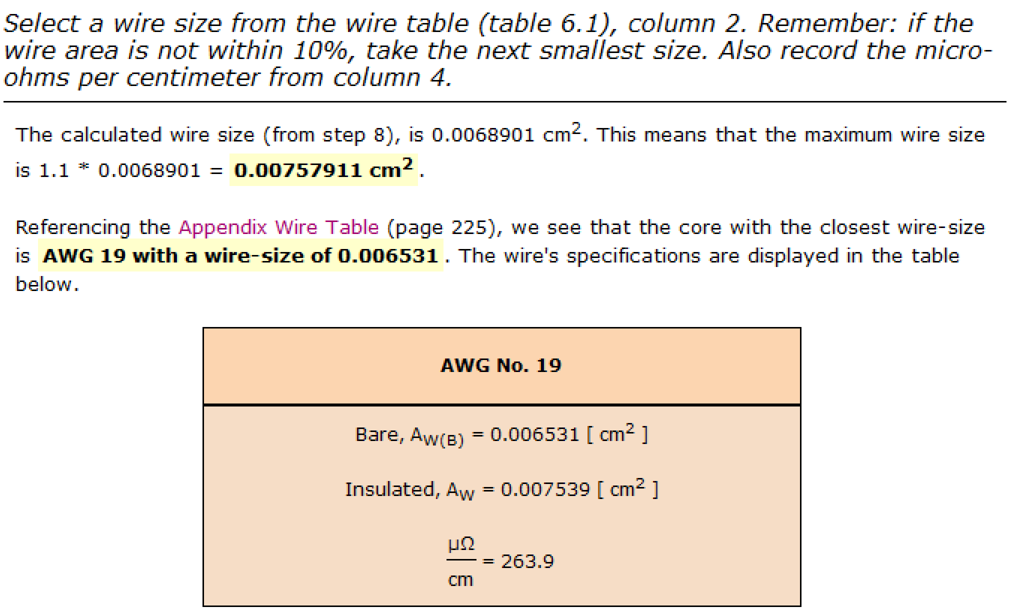


The calculated area product (from step 3), is 0.773804 cm^4. Referencing the Permalloy 2-mil table, we see that the core with the closest area product is **Core CL-7** . The core's technical specifications are listed in the table below.

Core CL-7			
A_p	0.95 [cm^4]	A_t	40.9 [cm^2]
MLT	4.7 [cm]	MPL	8.1 [cm]
A_c	0.47 [cm^2]	W_{tfc}	0.029 [kg]
W_a	2.02 [cm^2]		

Figure 4. Core is automatically selected based on the given technical specifications

When designing either a transformer or an inductor, a wire is required for the winding(s) around the magnetic core. Wire selection is typically based on the window area of the core as well as tolerable amount of copper losses in watts. The web-based magnetic design contains a sub-routine that automatically looks for the wire size (gauge) that most closely fits the calculated core material and type. However, since the program is meant to aid in basic calculations of simple inductor and transformer designs, the wire selection does not take into account complex configuration of winding such as bifiliar or more, interleaving, etc. Figure 5 illustrates the step where wire size is determined including three data related to the selected wire size for user's reference.



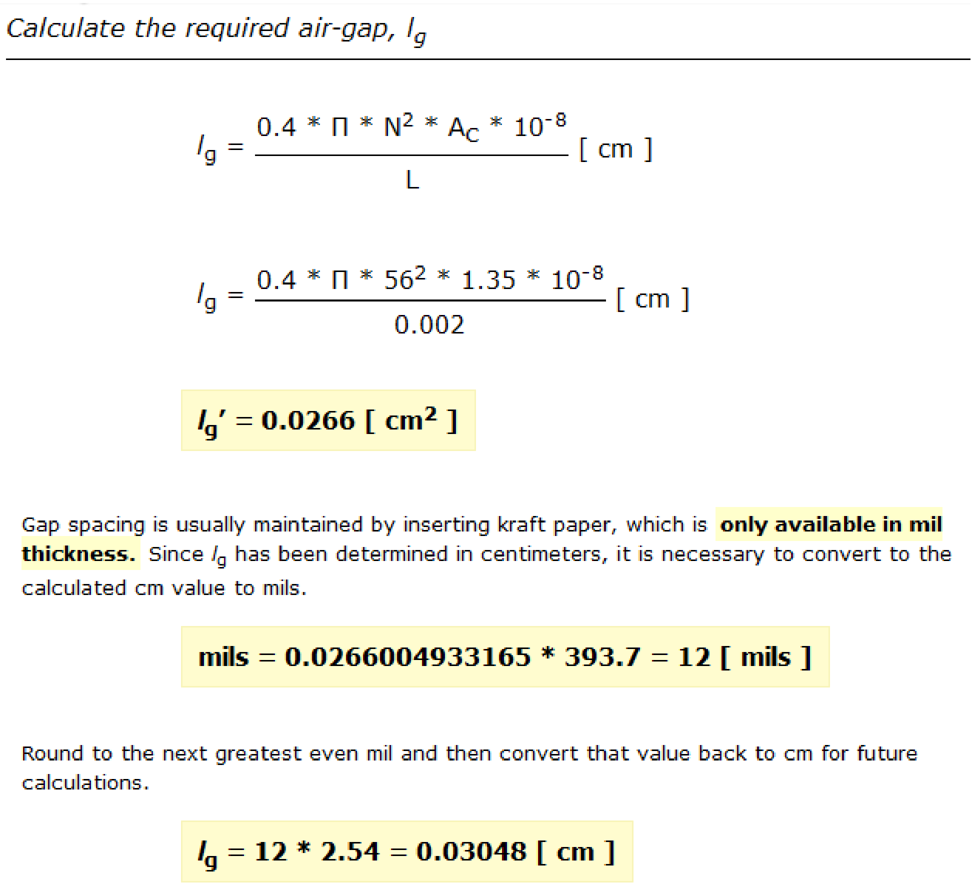
Select a wire size from the wire table (table 6.1), column 2. Remember: if the wire area is not within 10%, take the next smallest size. Also record the micro-ohms per centimeter from column 4.

The calculated wire size (from step 8), is 0.0068901 cm^2. This means that the maximum wire size is 1.1 * 0.0068901 = **0.00757911 cm^2** .

Referencing the Appendix Wire Table (page 225), we see that the core with the closest wire-size is **AWG 19 with a wire-size of 0.006531** . The wire's specifications are displayed in the table below.

AWG No. 19
Bare, $A_{W(B)} = 0.006531$ [cm^2]
Insulated, $A_W = 0.007539$ [cm^2]
$\frac{\mu\Omega}{cm} = 263.9$

Figure 5. Wire size selection



Calculate the required air-gap, l_g

$$l_g = \frac{0.4 * \Pi * N^2 * A_C * 10^{-8}}{L} \text{ [cm]}$$

$$l_g = \frac{0.4 * \Pi * 56^2 * 1.35 * 10^{-8}}{0.002} \text{ [cm]}$$

$$\mathbf{l_g' = 0.0266 \text{ [cm}^2\text{]}}$$

Gap spacing is usually maintained by inserting kraft paper, which is **only available in mil thickness.** Since l_g has been determined in centimeters, it is necessary to convert to the calculated cm value to mils.

mils = 0.0266004933165 * 393.7 = 12 [mils]

Round to the next greatest even mil and then convert that value back to cm for future calculations.

$$\mathbf{l_g = 12 * 2.54 = 0.03048 \text{ [cm]}}$$

Figure 6. Air-gap calculation

One type of inductor that is treated separately in the web-based design is the gapped inductor type. For this type of inductor, there exists a gap in the core to enable increased energy storage, but at the expense of loss due to fringing flux flowing across the gap. This gap in practice may be established by inserting materials such as kapton tape or kraft paper. The web-based design assumes that the gap is introduced by kraft paper which is available only in mil thickness. Figure 6 depicts this step.

Conclusion

The automated Magnetic Design Web Application, available at http://www.magneticdesign.org, generates the full design process of a power transformer, gapped inductor and toroidal inductor given design specifications provided by the user[8]. Calculations are accomplished using Area Product (Ap) or Core Geometry (Kg) procedures. An administrative backend is provided where instructors can add or modify core design values to expand the array of materials used. The web-based magnetic design aims to aid student's understanding of magnetic design and course concepts while allowing instructors to broaden the scope of material covered within magnetic design course. Although the web-based design is meant for use in undergraduate level magnetic course design, its content is presented such that any practicing engineers who desire to learn the basic inductor and transformer designs may also find the web-based design useful. Further work includes addition of more magnetic core data into the web core database and a class survey to assess the usefulness of the web-based tool for students taking the magnetic design course.

References

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