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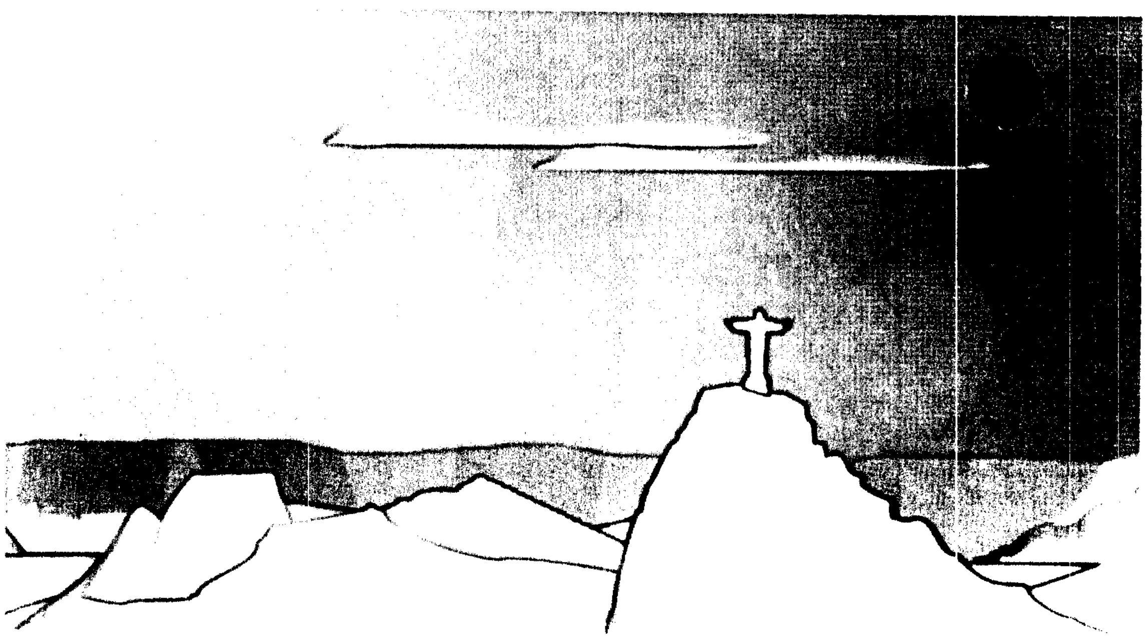
PART I OF TWO PARTS



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CAT: Computer Assisted Teaching in Magnetics

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***Abstract* — Starting with the 3rd academic year the students taking electrical energy as their major subject at the K.U.Leuven are following theoretical lectures and laboratory sessions supporting the basic knowledge on the finite element method (FEM). The numerical sessions take place in front of workstations. The students are working with commercial FEM program packages and the numerical sessions are always followed by a practical laboratory measurements. Here, the students have to measure the beforehand computed results such as currents, induced voltage and inductances of simple magnetic circuits. In the following 4th academic year more complex tasks are demanded such as computations of dc machines or ac induction machines. For a better insight into the physical behavior and to make the field solutions of induction machines understandable, a multimedia software program is available to the students distributed via the Internet. The methodology of the step by step approach of computer assisted teaching, performed at the K.U.Leuven, to transfer the knowledge of the complex numerical field computation techniques are discussed.**

***Index terms* — engineering education, electromagnetic analysis, finite element methods, multimedia system.**

I. Introduction

The skills that should be teached to the engineering students are very complex and manifold. Learning is one of the hardest tasks to fulfill and thus, the university institutes have the duty to wake up enthusiasm in the student by choosing the right tools for teaching and knowledge transfer. The difficulty always is to choose an appropriate form to teach sophisticated and inherent very abstract subjects such as numerical techniques. Applied to power engineering problems a complex mathematical background and a deep physical understanding is recommended to be able to follow the courses and to collect the knowledge and experience for a successful later professional engineering carrier. In this paper the authors like to show their way of teaching the theory and application of numerical field computation methods in the power engineering division of the Katholieke Universiteit Leuven.

The well known abbreviation CAE (computer aided engineering) is regularly used to describe engineering techniques aided by digital computers. Thus, activities of industrial or university engineers to solve design problems or calculate and predict the behavior of physical technical products such as electromechanical energy converters are part of this definition. Due to constantly decreasing prices of standard computer hardware and software, powerful PC's now can be found in nearly every student-household. The possibilities of easy access information at anytime from nearly every place in the world via the Internet are increasing as well. As a reaction and to ensure the equal opportunities the Katholieke Universiteit Leuven is renting students hard and software by a subsidized fee. As a consequence, the university teaching staff includes computer-aid tools into the lectures and laboratory sessions. Therefore, the new abbreviation CAT can now be used for Computer Assisted Teaching.

II. Electrical Engineering at the K.U.Leuven

Starting from the basic idea that electromechanical engineering students should be educated to address the wide variety of problems related to the production, distribution and use of electrical energy in all aspects, a curriculum is set up with a broad spectrum, in order to avoid a too narrow specialization. A specialization into the field of electromagnetics and their associated problems and methods is carefully done over a period of two years. This curriculum has to be fitted into boundary conditions as set by legislation and the university. The total study time (including a master thesis during the last year) is 5 years. Per year, the students have to pass a maximum of ten examinations. The first two years, the so-called candidatures, are common to all engineering students. The last three technical years lead to the title of electromechanical engineer and his specialization.

Basically, two streams in electrical engineering education can be followed:

- power and
- information technology.

The technological progress in information technique seems to be larger when compared to the power engineering

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sector. This implies and may give students the illusion that in the information technique more advanced and newer techniques are used to solve the specific problems in this engineering direction. It attracts undergraduates and explains the difference in the total number of students per academic year in most of the universities choosing for this engineering field and not for the power engineering education. However, at the Katholieke Universiteit over the last years a constant number of students per year in the power engineering division can be counted. By assuming a decreasing total number of electrical engineering students this means a constant positive overall gradient for the power engineering division ESAT/ELEN. The authors think that a main reason for this positive gradient can be found by introducing new and modern methods and techniques to solve problems in classical subjects like electrical machines, high voltage and electroheat to the students. At the K.U.Leuven recent education tools such as multimedia computers and programs [1] are used to support the individual learning capabilities of the students.

Close contacts between the university institute and industry are necessary to support the feeling of the students to work in a technical field of social importance. Part-time stays of students in industrial companies during lecture free periods are essential to enable the chance to see practical engineering problems and to judge with this practical knowledge how the university prepares the young engineer for his/her future. The classical subjects all power engineering students at the Katholieke Universiteit Leuven have to follow are (Fig. 1):

- power systems,
- electroheat and
- electrical machines and drives.

The listed subjects are not separated from each other. They have to be seen as a unit with the linking subjects such as CAD techniques and the control theory. With this link an interdisciplinary teaching is obtained. A strong link to the mechanical engineering department of the K.U.Leuven ensures that all items concerning the term energy are treated as complete as possible.

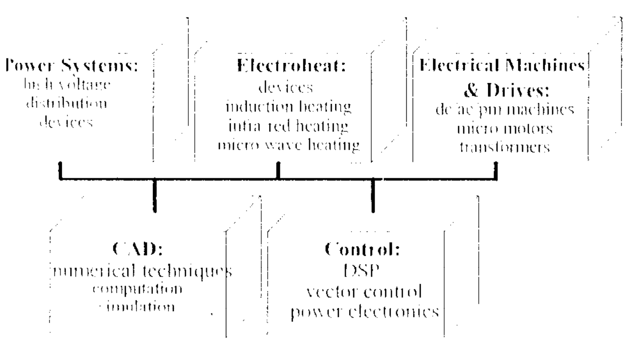

Fig. 1. Curriculum of the electrical power engineering students at the K.U.Leuven

Furthermore, courses developed and given for engineers from industry can be found in the teaching program of the division ESAT/ELEN (Fig. 2). An annual course on electromagnetic fields, given for engineers out of industry, is one attempt and effort to train engineers in a complex item such as numerical field computation theoretically and in practical laboratory sessions as well.

To complete the program of presentations to industrial engineers and interested students, several study days and evening lectures are organized during the academic year in the frame of the Royal Flemish Engineering Society (KVIV).

III. A Step by Step Approach

The complex knowledge of numerical techniques is transferred on different levels of difficulty. A distinction between high level, the knowledge on matrix level, intermediate and basic skills, understanding of the functionalities of the method, must be made to reach and succeed in teaching different target groups. Students of the different fields of engineering science and engineers already working in industry are the target groups that have to be reached.

In general, universities have a threefold duty:

- transfer of knowledge to the society, teaching
- placing scientific service at the society's disposal
- academic and applied research

All the mentioned points are linked to teaching. The transfer of knowledge is mainly done by instructing students from undergraduate up to the doctorate level.

A short course in 'CAD in magnetics' is given annually to interested engineers from industry and/or researchers from other universities. The training of such already educated engineers from industry by giving this annual short courses can be linked to the first two points in the list.

Research finally influences the content of the teaching material and contributes to the first point as well.

To fulfill the threefold duty, it is necessary to split the knowledge to be transferred into three levels of difficulty in a didactically straight forward way as indicated in Fig. 3.

The first course on electrical drives where the students are confronted with numerical methods is called Electrical Machines part II. Here, different topics are treated, dealing

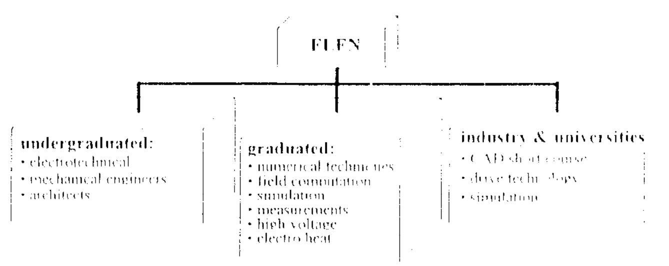

Fig. 2. Teaching activities ESAT / ELEN

with the function, parasitic effects and the design of the device itself. For the design and optimization of an electromagnetic apparatus the numerical tools are essential and this is shown to the student in this stage of his/her university studies. Design aspects, specifically in permanent magnet excited machines and induction motors are discussed very detailed and are accompanied by practical computations in the laboratory.

The aims of the three level structure used at the K.U.Leuven, with other words the three steps in teaching students in magnetics, are collected in Table I.

A. Level I

To enter level I, the corresponding target group has to be prepared. Therefore, in this entry level it is explained where the numerical field computation has its origin and place in a design process. Different approaches to calculate electromagnetic fields are discussed and advantages and disadvantages of the classical analytical models of the field approximation have to be studied in theoretical lectures. The various pure numerical methods such as FDM, FEM, BEM (Table II) are discussed in more detail to demonstrate their performance and application range.

This step is accompanied by studying the working principles of electromechanical energy converters to transfer a feeling to the students of how a field behaves inside the device and of which order of magnitude the various calculated quantities are expected. Along with the lectures on electrical machines, the students can work at a computer with a multimedia tool to understand the operating principles of an induction machine. This study period is performed before they start to solve the associated field problems numerically. The multimedia software tool is developed by the group at the K.U.Leuven [2] and distributed via the Internet and can be downloaded by the students at any time [1]. With this software the theory and construction of the induction machine can be studied individually. Graphical representations of the induction machine can be discovered by simple mouse clicks to get further and more detailed information from a certain part of the machine. Fig. 4 shows the construction of the squirrel cage winding. Two buttons can be pressed to obtain more information about the cage winding itself or about the iron lamination of the rotor. The multimedia tool met with the students of the 3rd year approval. Actually a software is under development to deal with the dc machine.

A secondary effect is obtained by distributing the software via the Internet and letting the undergraduates work with it. Even nowadays, there are students not used to work with a computer and they are loosing the uncertainty with this device in this way.

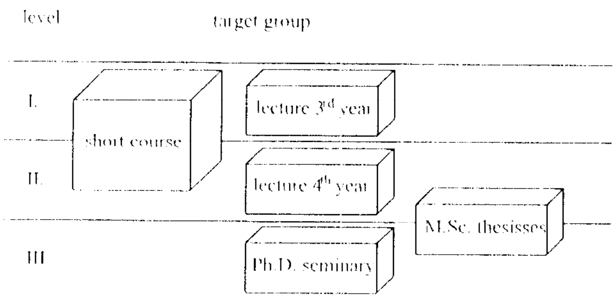

Fig. 3. Target groups and related levels in teaching.

TABLE I
AIMS AND STEPS IN TEACHING COMPUTATIONAL MAGNETICS

level	target group	aim
I	a) undergraduates 3rd year b) engineers out of industry	• basic theoretical knowledge of numerical field computation methods • capability to solve simple standard electromagnetic static and time-harmonic field problems in 2D
II	c) undergraduates 4th year d) (partly) engineers out of industry	• advanced theoretical knowledge of numerical field computation already on matrix level • numerical optimization algorithms • design theories and methodologies • capability to solve more complex field simulation tasks in 2D and simple problems in 3D
III	e) Ph.D. students f) program developer	• extended theoretical knowledge on matrix and program level • knowledge of data structures • capability of handling data to obtain own solution algorithms • programming own software routines • capability to solve advanced 3D problems

TABLE II
FIELD COMPUTATION METHODS(1)

method	principle of discretization	geometry approximation	non-linearities	computational costs
FEM		extremely flexible	possible	high
FDM		inflexible	possible	high
BEM		extremely flexible	troublesome	high
MEC		specific geometries	possible	very low
PMM	m_1 • q m_2 • q'	simple geometries	by constant factors	low

(1) FEM - finite element method, FDM - finite difference method, BEM - boundary element method, MEC - magnetic equivalent circuit, PMM - point matching method

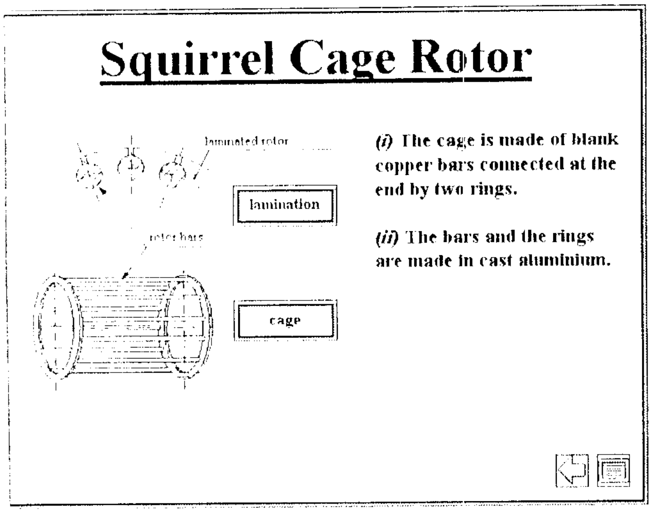

Fig. 4. Induction machine construction detail representation of the multimedia tool INDUCTUTOR [1].

To support the understanding of the physical behavior of the technical devices treated in the lecture and the methods to calculate them, practical CAD sessions at the computer are hligatory. Here, simple 2D computations are performed ising a commercial FEM program package. Examples are hosen to point out the connection between analytical, umerical and measurements in particular.

3 Level II

After the entry level, a basic understanding of the physical device and its numerical treatment can be assumed. Now the umerical problems and all neglections assumed are part of the lecture. More and more numerical details are illuminated. simple 3D computations are performed in the CAD sessions o demonstrate the differences with the 2D approximation. ther methods combined with the FEM such as optimization lgorithms are introduced as well.

A master thesis can be written in the field of numerical chniques as well. Here, further theoretical knowledge and lvanced skills in using a finite element program package is btained. The thesis student usually has to code own ftware routines to investigate specific algorithms or umerical methods.

Level III

The last step of this four year lasting program is reserved the doctorate level. The theory of the method is presented the matrix and program organization level. Here, special oblems such as error estimation, mesh adaptation chniques, solver strategies etc. are treated. The capabilities coding specific parts in field computation programs are ained as well. A special seminar is given to prepare the students for this level. Several theoretical lectures are given by the Ph.D. students himself.

IV. Conclusions

Classical fields of engineering, such as electrical power systems and electrical machines and drives, tend to suffer from a lack of interest by the students. They are attracted by more glamorous subjects, such as electronics and mechatronics. Electrical energy and its applications and devices are, however, an essential if not indispensable part of every day life and of all manufacturing systems. Therefore, it is strongly recommended to develop an education that attracts the students of today. A constant number of students, by assuming a decreasing number of electrical engineering students, choosing for energy as their main subject, shows that a classical subject such as electrical machinery filled with modern and up-to-date items such as numerical methods, indicates the right way of university education.

A CAT program to teach electromagnetism is described which, always carefully updated, successfully runs for a couple of years already. A comparable approach is chosen for other subjects in the power engineering education at the K.U.Leuven [3].

To enhance the educational offer of computer learning or teaching tools a distance learning tool, introducing the finite element method, is under development in Leuven. Students are working on this new project with great enthusiasm.

During several stays at universities in different countries such as Great Britain, Canada, Germany, Algeria and Brazil the authors collected experiences in teaching such complex subjects to assemble it into an homogeneous curriculum for electrical power engineering students art the Katholieke Universiteit Leuven in Belgium.

Acknowledgment

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