A ROMANIAN EXPERIENCE IN COMPUTER-AIDED ELECTROMAGNETIC EDUCATION

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Abstract

The paper presents the actual interests in computer-aided electromagnetic education (CAEE) at the Electrical Engineering Department from Polytechnic Institute of Bucharest, Romania.

The actual state of computer use on different levels of undergraduate and graduate education is presented. Specifically, an overview of the undergraduate theoretical training and practical applications is described, and research topics for graduate reports and doctoral dissertations are discussed. Issues related to hardware utilities are reviewed, and future projects aimed at improving the CAEE capabilities in Romania are described.

The material is based on significant selected references.

1. Introduction

The Polytechnic Institute of Bucharest is the oldest and most dominant engineering school in Romania. With a history of more than one hundred years, the Institute is composed today of several departments, including Electrical, Mechanical, and Chemical Engineering, Computer Science, Materials Science, etc. [1].

The Electrical Engineering Department is organized to train about 250 graduates (M.S. engineer equivalent) and 5-10 postgraduates (Ph.D. equivalent) a year in domains such as electromechanical devices, electrophysics, electrotechnologies, electrical drive systems, measurement, and management.

The history of the computer impact in engineering education started approximately 25 years ago with the study of the programming language Fortran. The applications were possible on an old IBM-1130, the first computer at the Polytechnic Institute of Bucharest and several Hewlett-Packard "computing machines," which seem to be very old fashioned now but released a lot of passions among students at that time.

Year by year, the importance given to computers in education increased, so that it became usual to find homework, current projects, and especially graduation reports and doctoral theses having a strong numerical basis.

This paper presents the actual state of computer use on different levels of education at the Electrical Engineering Department from the Polytechnic Institute of Bucharest. The relevant educational software packages in the CAEE area developed in this department are presented.

2. Fundamental Grounding

The undergraduate studies in the Electrical Engineering Department covers 10 terms, each of 14 weeks length of time. The timetable covers weekly 30 hours on an average (about 50% lectures and the other 50% applications: laboratories, seminars, and projects). Usually, the curriculum offers about 75 disciplines, 45 of them being compulsory and 5 at the student's choice. The last term is dedicated to the completion of the graduate final report.

Of great interest for CAEE are the following branches:

- mathematics
- physics
- computer science
- fundamentals of electromagnetics
- electronics
- electrical apparatus, machines, and drive systems.

The **mathematical disciplines** are studied during the initial three terms and in about 420 teaching hours (lectures and seminars). These studies cover a large area including: linear algebra, geometry, analysis, complex functions, vector field analysis, integral and differential equations, and integral transforms.

Physics is studied during the initial five terms and its main topics are: mechanics, statistics and thermodynamics, quantum mechanics, fluid flow, and materials science.

Computer science study has the following stages:

- *computer programming* -- the Pascal language is studied during the first and second terms, in 42 lecture hours and 56 laboratory hours
- *programming techniques* -- during the third term (28 lecture hours and 14 laboratory hours), the students are initiated in data structures and non-numerical algorithms (pointers, lists, stacks, ques tries, graph finding and sorting techniques, etc.)
- *numerical methods* -- in the fourth term (42 lecture hours and 14 laboratory hours), the main numerical algorithms with specific applications in electrical engineering (linear equation systems, interpolation and approximation of functions, nonlinear equations and systems, numerical derivation and integration, ODE, and PDE)
- *digital systems* -- in the fifth term (28 lecture hours and 14 laboratory hours)
- *microprocessor programming* -- (28 lecture hours and 14 laboratory hours) in the fifth term
- *Microprocessor systems* -- structure and functions are studied in the eighth term (42 lecture hours and 28 laboratory hours).

Fundamentals of **electromagnetics** with the main interests in:

- *electrical circuits* -- (84 lecture hours and 70 application hours) during the third and fourth terms
- *electromagnetic field* -- in the fourth and fifth terms (84 lecture hours and 42 application hours), the study is directed to Maxwell's equations and the specific time dependencies for EM fields
- *system theory* -- studied during the fifth term (42 lecture hours and 28 application hours).

The most relevant course in this stage is "Numerical Methods in Electrical Engineering" [4, 5]. Despite it being at an introductory level, this course combines elements of numerical analysis, programming techniques, and methods for computer analysis of electric circuits and electromagnetic fields. For the laboratory associated with this course, the Electrical Engineering Department developed a computer-aided learning package named **NUMEE** (Numerical Methods in Electrical Engineering). This package contains 25 lessons and covers the following topics:

- *numerical algorithm analysis and mathematical data structures* (error propagation, complexity of the algorithms, abstract data types, etc.)
- *algebraic linear systems* (Gauss method, pivoting strategies, LU decomposition, sparse matrix techniques, iterative methods) with application to the linear electric DC and AC circuit analysis
- *approximation and interpolation* (polynomial interpolation: Lagrange, Newton, Thebishev, piecewise polynomial interpolation: spline, Bessel, Akima, least square approximation)
- *function derivation and numerical integration* (divided differences of different orders, backward, forward or central, integration by trapezoidal, Simpson, Romberg, Gauss methods)
- *nonlinear equation solving* (Newton, Picard, secant methods, etc.) with application to the DC nonlinear electric circuits
- *ordinary differential equations* (implicit and explicit Euler method, Runge-Kutta) with application to the transient linear and nonlinear electrical circuit analysis
- *partial differential equations* (FDM -- finite difference method, FEM -- finite element method, and BEM -- boundary element method) with application to the static electric and magnetic fields
- *circuits and system numerical techniques* (Fourier transform, eigen values and vectors).

The laboratory class is carried out by students' practical participation. Each laboratory work begins with the execution of an illustrative program whose input data are entered by the student; e.g., solution of the Laplace equation by RDM in a square using Dirichlet boundary conditions (Fig. 1), solution of the Poisson equation by the REM in a circle using Dirichlet boundary conditions (Fig. 2), and computation of the electrostatic field generated by two plane parallel electrodes in free space using BEM (Fig. 3).

The program steps through the algorithm pointing out the effect of each step upon the initial data (e.g., the convergence of numerical solution in iterative process). The second part allows an estimate of the computing effort and accuracy of the algorithm using a standard set of input data (e.g., the computing time vs. the node numbers of the grid). The exact solution is compared against the numerical results. During the third step, the student must translate into Pascal the pseudocode algorithm from the laboratory guide and implement a short test program which solves a precisely defined simple problem. The last phase in the laboratory work consists of an automatic knowledge test.

The **NUMEE** has been developed in Turbo C environment and contains about 30,000 C lines. It can be run on an IBM PC or compatible computers. The educational experience gained using **NUMEE** is very encouraging. Contrasting to the study of a textbook, the students' interest in such a learning approach is higher.

3. CAEE Experience in Undergraduate Education

On the second stage of study, students begin to face the main engineering-like disciplines with an important applied nature, namely the electronic circuits and devices, electromechanical devices, and drive systems.

The area of **electronics** consists of:

- *electronic devices* -- in the fifth term (28 lecture hours, 14 seminar hours, and 28 laboratory hours)
- *electronic circuits* -- in the sixth term (56 lecture hours, 28 laboratory hours, and 28 design hours)
- *electric and electronic measurements* -- in the sixth term (42 lecture hours and 42 laboratory hours)
- *power electronic devices* -- in the sixth term (28 lecture hours and 14 laboratory hours)
- *power electronic circuits* -- in the seventh term (42 lecture hours and 28 laboratory hours).

The main topics in the **electromechanical** discipline are:

- *electrical machines* -- in the sixth and seventh terms (112 lecture hours and 84 laboratory hours)
- *electrical apparatus and devices* -- in the sixth and seventh terms (112 lecture hours and 70 laboratory hours)
- *electrical drive systems* -- in the seventh and eighth terms (84 lecture hours and 84 application hours: seminar, laboratory, and design).

The ordinary training in different domains is completed by several optional disciplines. The undergraduate students perform homework and terminal projects. Some of them prefer to integrate in their works small codes, created by themselves on personal computers or one the department computers available to them. The most usual problems treated in that way are:

- electrical circuit problems
- material properties simulations
- optimization criteria in design of electric machines and apparatus
- several design methodologies, usually the iterative ones
- simulation of different working conditions of drive systems
- statistical or graphic postprocessing of experimental measurements.

The quotation system for student work encourages these sorts of computer applications, because they require both a proper and adequate formulation of the EM problem and the finding of the right numerical method to solve it. At the same time, we noticed a remarkable increase in self confidence and an appetite for improvement in computer knowledge. The references used are classical ones and include specific textbooks, such as [2, 3, 4, 5].

The coordination of several term projects on electrical machines (d.c. motors, power transformers) is partly organized based on computer codes with the following structure [9, 10]:

- preprocessing of some specific data (the project subject)

- development of a design methodology for main electromagnetic and geometric estimate
- economic optimization, if necessary
- electromagnetic field computation
- postprocessing of results: working characteristics, graphic representations.

Many courses deal with electric/magnetic circuits simulated in different working conditions with linear or nonlinear elements. The specific code **RESEL** developed in the E.E. Department to solve this problem [11] has the following features:

- a description of the network topology using a **SPICE**-like language
- a description of the initial state and time-dependent supply sources
- postprocessing of the results: graphic presentation of any electric/magnetic signals.

Microprocessors in drive systems is one of the most application-oriented topic in EM education. Its laboratory and term projects are actual applications of digital control positioning systems [8]:

- design and implementation of control procedure
- numerical simulation of positioning systems
- implementation of digital control system (software and hardware architecture) with practical applications on a Z80 microprocessor.

4. CAEE Experience in Graduation and Doctoral Dissertations

Most graduate students and all doctoral students in engineering who have presented dissertations during the last 10-15 years paid great attention to computer applications on their EM problems. Here are some of the most important and recently elaborated topics:

(1) Electric and magnetic 2D and 3D field analysis associated with different geometric structures such as power transformers, electric machines (d.c. and a.c.), high-voltage insulators, high-current switches, devices used in technologies of composite materials, electrothermal systems, electrochemical devices, etc. [9, 13, 14, 15, 18].

The general structure of such dedicated codes allows:

- input data-geometry of domain, initial and boundary conditions, description of field sources and material properties
- numerical treatment of specific field equations and boundary conditions (finite difference, finite element, integral form methods and hybrid methods are frequently used)
- solution of large linear or nonlinear algebraic system of equations
- postprocessing of solutions: computation of losses, energy, mechanical stresses, field line representations, evaluation of electric and magnetic circuit parameters, etc..

(2) General CAD/CAE packages, easy to use in design work, combining the design methodologies with EM field and circuit problems and the economical optimization in problems like electronic analog and digital circuits, power apparatus, electric machines, drive systems [12, 13, 15, 18].

(3) Dynamic answer of electromechanical systems based on Fourier transform spectral methods [16, 17]:

- electrical measurements with signal processing
- nondestructive diagnosis of failures in high-power transformers and electric machines
- monitoring techniques and diagnosis of drive systems.

One relevant package, initially developed as a graduate requirement, is the "Field Analysis Program -- **FAP**" [19, 20]. This software package is dedicated to education in the CAD/CAE area. **FAP** allows analysis of the two-dimensional field in linear media, being characterized by the Poisson equation with a Dirichlet, Neumann, or Robin boundary condition using the finite-element method. The programs run on an IBM PC/XT/AT and compatible computers and have a strongly interactive user interface. **FAP** may be applied to the electric, magnetic, and thermal field analysis in different devices. It consists of:

FPR -- graphic preprocessor
FED -- problem editor
FCL -- linear problem solver
FDO -- graphic postprocessor.

The programs are chained by a driver named **FAP**, thus creating an integrated environment.

The problem to be solved is described in an interactive way, using the graphic preprocessor **FPR** and problem editor **FED**. In **FPR** the geometric and topological data is inputted. Automatic and manual grid general is allowed. Each homogeneous domain is identified by an alphanumeric label and represented on screen using a specific graphic pattern. **FED** allows the input of source and material values associated to a different label used in **FPR** (Fig. 4).

The following commands are available in the preprocessing stage:

The problem solver **FCL** uses the geometric and topological data generated by the graphic preprocessor and the physical values given by the problem editor to generate the linear equation system specific to the finite-element method. The system matrix is a sparse one, and a special storage technique is used. The linear equation system is solved using either the SOR method or conjugate graduate method. Since the solver uses dynamic memory allocation, the problem size is limited only by the available computer memory. On a 640-KB IBM PC, problems can be as large as 5000 elements. The **FPO** postprocessor uses geometrical data from the **FPR** preprocessor, and the solution given by the solver **FCL** allows the obtaining of an image of the analyzed device as well as a wide variety of output options. This includes (Fig. 5):

- local values of potential, field strength in magnitude, modulus, and by components
- integral values on curves/surface like electric or magnetic flux
- global values like energy, force, and torque computed or specified domain
- graphical representation of the solution along the user-defined line segment
- 3D graphical representation of the solution.

The software package **FAP** was successfully used in education. It allows the modeling of electric and magnetic devices such as actuators, electric machines, electrochemical devices, magnetic shielding problems, etc. (Fig. 6).

Unfortunately, in the Polytechnic Institute of Bucharest there is no organized form of postgraduate courses for the Ph.D. candidates. There is also no form of long-term or continuous postgraduate education. With the object of exceeding this stage, a TEMPUS project entitled, "Initiation of Formal Training in Computer-Aided Electrical Engineering in Romanian Universities" and coded JEP 2717, is granted by the European Community. The main goal of this Joint European Project is to establish a postgraduate school containing a training and documentation center in the area of CAD/CAE, both for electromechanical devices and for electronic circuits, including VLSI circuits. The institutions involved in this project are: Politecnico di Torino, Institute National Politechnique de Grenoble, University of Bath, Universita di Genova, Universita di Cassino, Universite de Paris, and Technische Universitat Graz.

The first year of the project, 1991-92, is dedicated to the organization of the Training Center: laboratory design, equipment and CAD software purchase, selection of teachers, language courses, and mobility of Romanian professors to EC countries for retraining and updating. The activities during the subsequent two years will include the beginning of the training, computer-aided learning software development, mobility for the Training Center's students, and mobility programs for foreign professors teaching in Romania.

The postgraduate training center will have two main directions of study: electromagnetic fields and electric/electronic circuits. A team at the Polytechnic Institute of Bucharest continued the development of a CAL package for numerical methods in order to enhance its suitability for the needs of postgraduate education.

5. Hardware Utilities

The recent surpassed historical period for the Romanian society -- the communist dictatorship -- was very unfavorable to the extent of the modern electronic utilities, especially the computational equipment. This happened in a moment of spectacular revolution of the world technical level.

That is why, at the beginning of 1990, the majority of the computers in use at the Polytechnic Institute of Bucharest were microcomputers on 8 bytes with 8080 or Z80 microprocessors, Sinclair compatibles, or using the old operating system CP/M. Many of these were bought through considerable personal effort by the professors and were made available to the students. Some IBM-PC compatible systems were far from satisfying the demands. The Polytechnic Institute of Bucharest, an institution with over 28,000 students, even now does not have the capability to use powerful Unix workstations. Starting with 1990, the development of several projects with the purpose of improving computing utilities has begun [7].

The Department of Electrical Engineering acquired, at the beginning of 1990, around 40 IBM-PC/AT compatible microcomputers, the majority coming from the Far East, with the main performances: CPU 8088; 1 MB RAM; 20 MB HDD, 1.2 MB FDD, Hercules monochrome graphics card.

In 1991, the department acquired 3 Novell LANs with 12 terminals each, dedicated to specific class applications for students in the early years. The networks are made up of a file server IBM PS/2 386 and IBM PS/2 model 30 terminals; the operating system is Netware 3.11 + DOS 3.3.

In 1992, there are several new projects under consideration:

- **DFN-Verein** project, which consists of the making up of a local network interconnecting the three campuses of the Polytechnic Institute of Bucharest. The infrastructures will be made of optic fiber, which allows a future increase on information transfer. Through the TCP/IP protocol, it will be possible to include the Novell cluster and other terminals. This project is a joint venture between the Polytechnic Institute of Bucharest and the Technical University of Darmstadt. It has a budget of 373,000 DM, most of it coming from the German government.

- The acquisition of Unix workstations is another important need for the Polytechnic Institute of Bucharest. The lack of experience in this domain makes it difficult to choose the proper solutions. This is why the decision made for the moment provides for the acquisition of several types of workstations for the practical testing of their capabilities in correspondence with our working conditions. This way, it will also be possible to gain experience with hybrid networks. To start with, the following types for "entry-level" workstations were chosen:

  DEC Station 5000/25
  HP Apollo Workstation 9000/710
  HP-X Station 700
  Sun IPX
  Sun ELC
  Silicon Graphics -- Indigo
  IBM RS 6000/320H

  In 1993, the network will be extended with file servers and stations which proved to be most advantageous. This project is funded by the TEMPUS JEP 2717 budget.

Two other projects planned for future years are:

- **RUN** -- Romanian University Network, which deals with the network connection among the main Romanian universities

- **RRDN** -- Romanian Research and Development Network, which deals with the network connection among over 60 national research institutes and universities.

The main purpose of these projects is to connect Romania and its powerful potential in education and research to the international academic networks. In this case, the Polytechnic Institute of Bucharest will be the central national node and the front end of the international network.

6. Conclusions

In this paper, a variety of EM topics that interest us were discussed and the practical results which are obtained from our experience in computer-aided education were described. These efforts resulted directly from the enthusiasm, desire to learn, and desire for self improvement of our teachers and students. The theoretical background of our faculty and students is very powerful, while the available technical utilities (software and hardware) are far from satisfactory.

We also consider that a better organization of documentation would be very useful, and an improved distribution mechanism would both benefit the users (educational as well as research communities) and have a favorable impact on the promotion of successful research projects.

During the last several years, we have more and more signals from research and industry media that encourage us to insist on CAEE education for a better integration of our graduates in electrical engineering life as well as for the development of mutual research projects between academia and industry.

The experience gained until now (through the TEMPUS projects) shows clearly that one of the most important elements that ensures the success of educational projects is the cooperation between universities having the same professional interest. Therefore, we welcome new partners in our TEMPUS JEP and are open to cooperation with other higher educational projects in the CAEE area.

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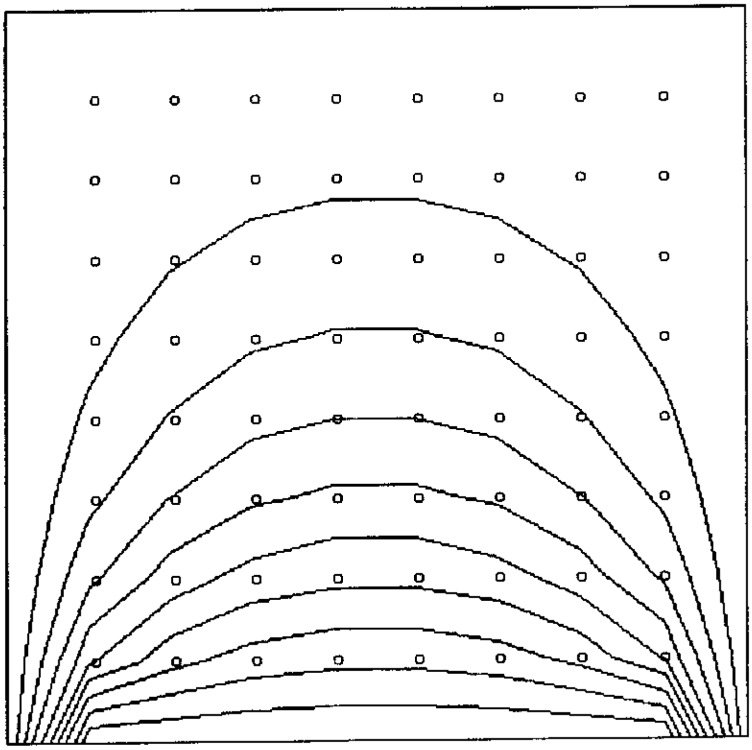


Fig. 1. Equipotential lines obtained by FDM.

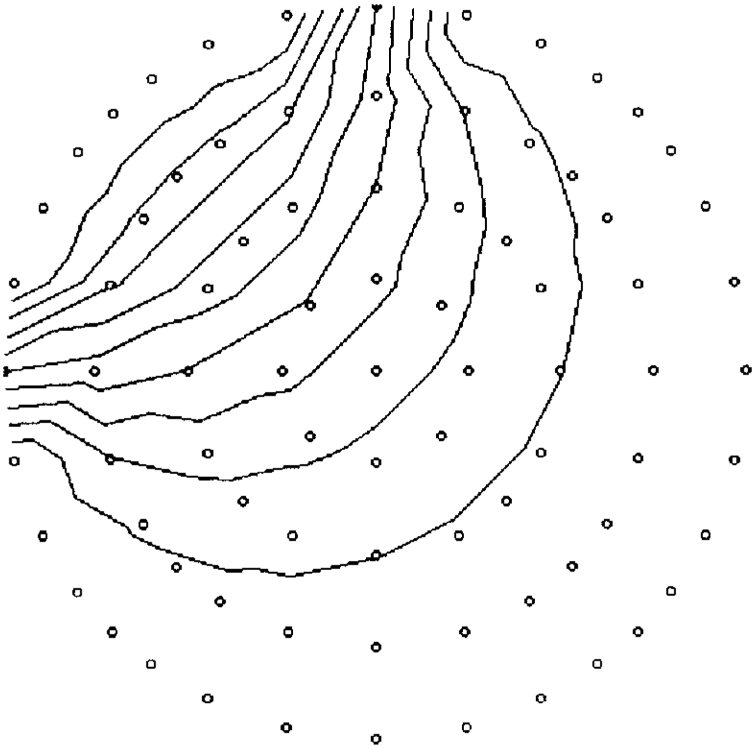


Fig. 2. Equipotential lines obtained by FEM.

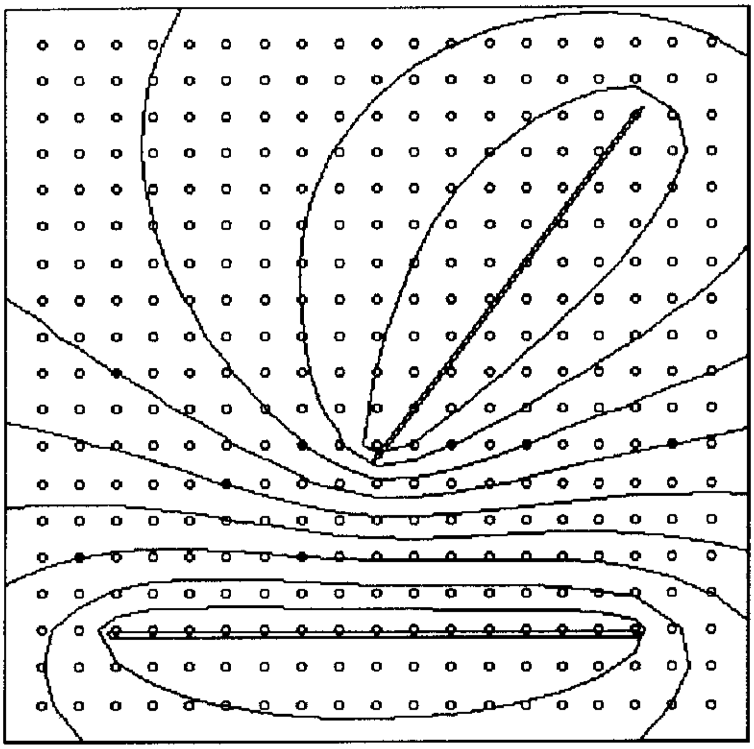


Fig. 3. Equipotential lines obtained by BEM.

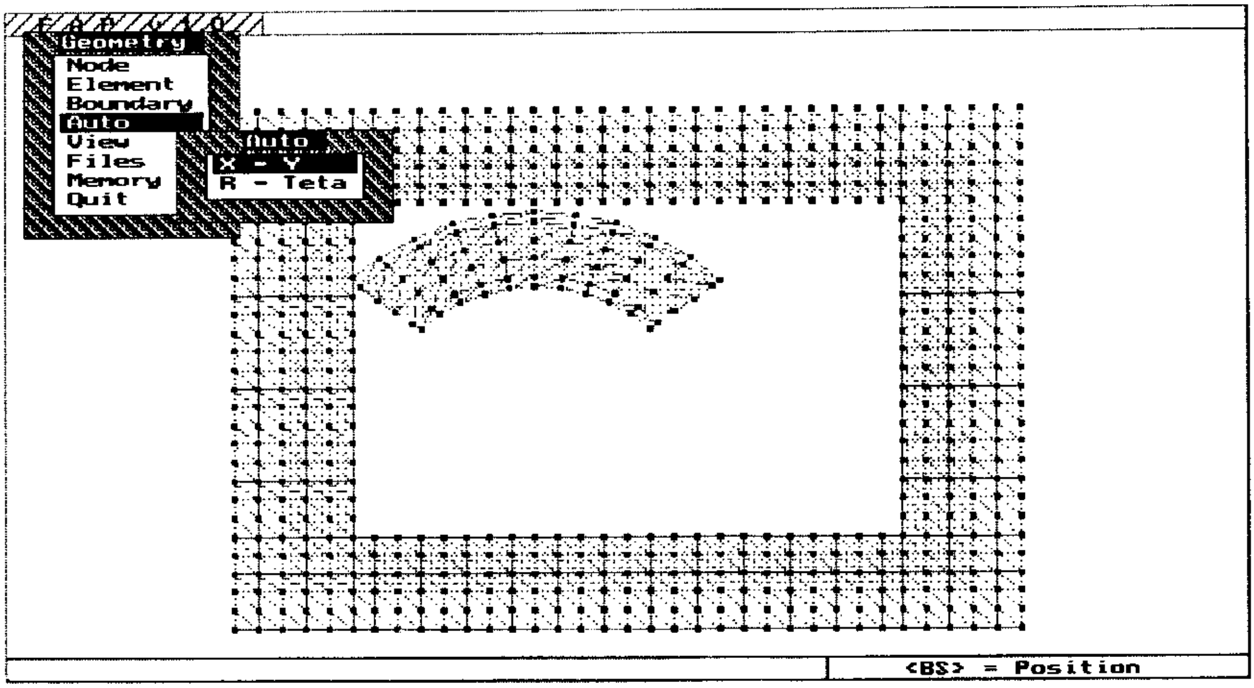
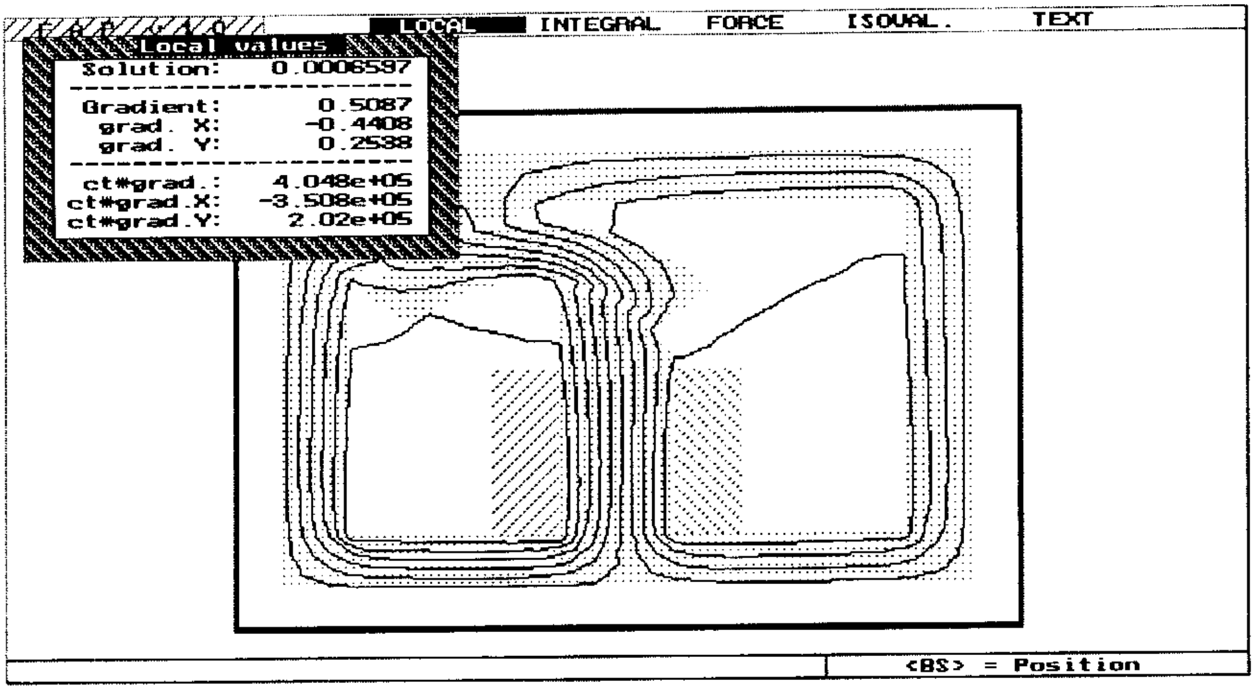


Fig. 4. Automatic mesh generation.



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Local values
Solution:    0.0006597
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Gradient:       0.5087
 grad. X:      -0.4408
 grad. Y:       0.2538
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ct*grad.:    4.048e+05
ct*grad.X:  -3.508e+05
ct*grad.Y:    2.02e+05
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Fig. 5. Postprocessor screen sample.

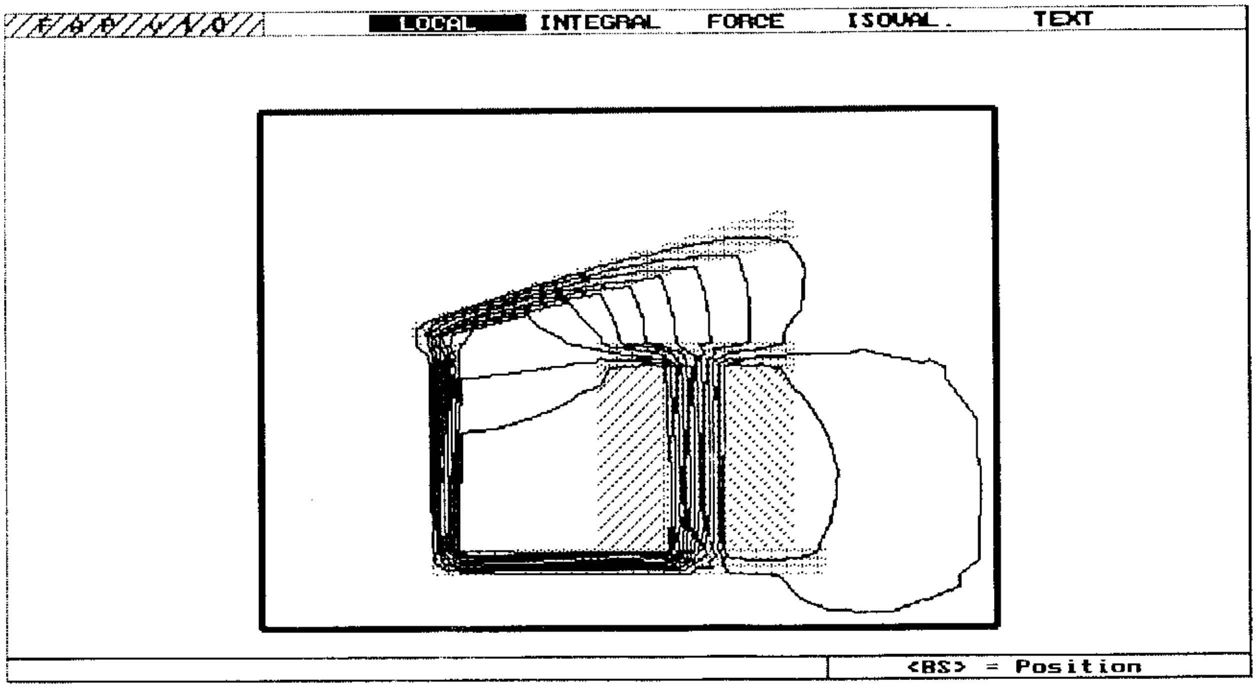

Fig. 6. Magnetic field lines of an actuator.