



CURS

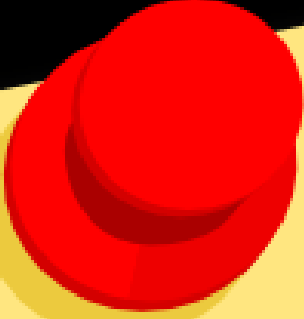
Proiectarea optimală a mașinilor electrice

– prezentări ppt. –

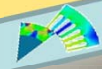
Conf. Leonard Livadaru

Universitatea Tehnică Iași

2020-2021



Introducere in
Metoda Elementului Finit



Dep. Elec. Machines

2020-2021

FEM with FLUX

Fenomene fizice



Ecuatii diferențiale



Metode analitice

Metode numerice

Metode
exacte

(transformata
Laplace)

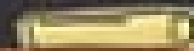
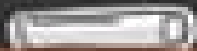
Metode
aproximative

(Rayleigh-Ritz,
Galerkin)

Metoda
diferențelor
finite

Metoda
elementelor
finite

Metoda
elementelor
de frontiera



Ce este metoda elementului finit?

INGINERIE

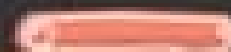
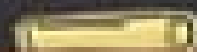
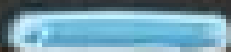
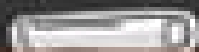
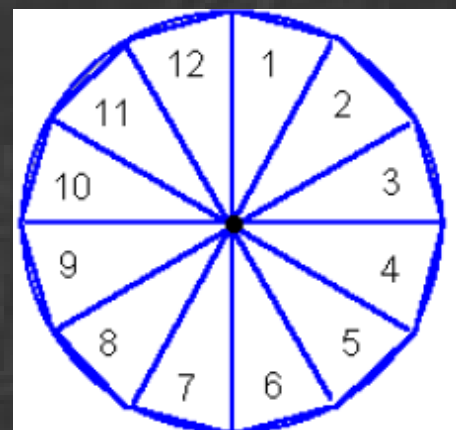
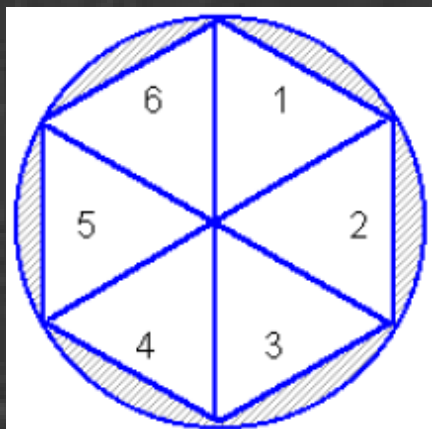
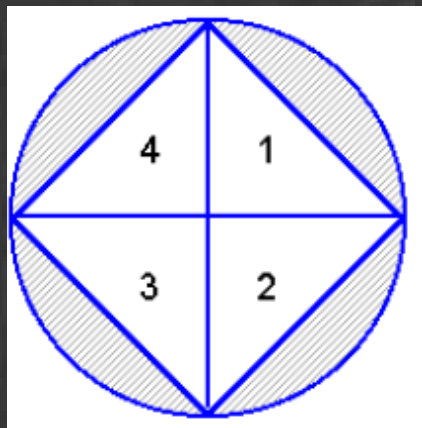
MATEMATICA

METODA ELEMENTULUI FINIT – MEF

FINITE ELEMENT METHOD – FEM

FINITE ELEMENT ANALYSIS – FEA

- Metoda numerica de calcul
- Obținerea unei soluții aproximative pentru ecuații cu derivate sau derivate parțiale ce sunt înlocuite cu ecuații algebrice

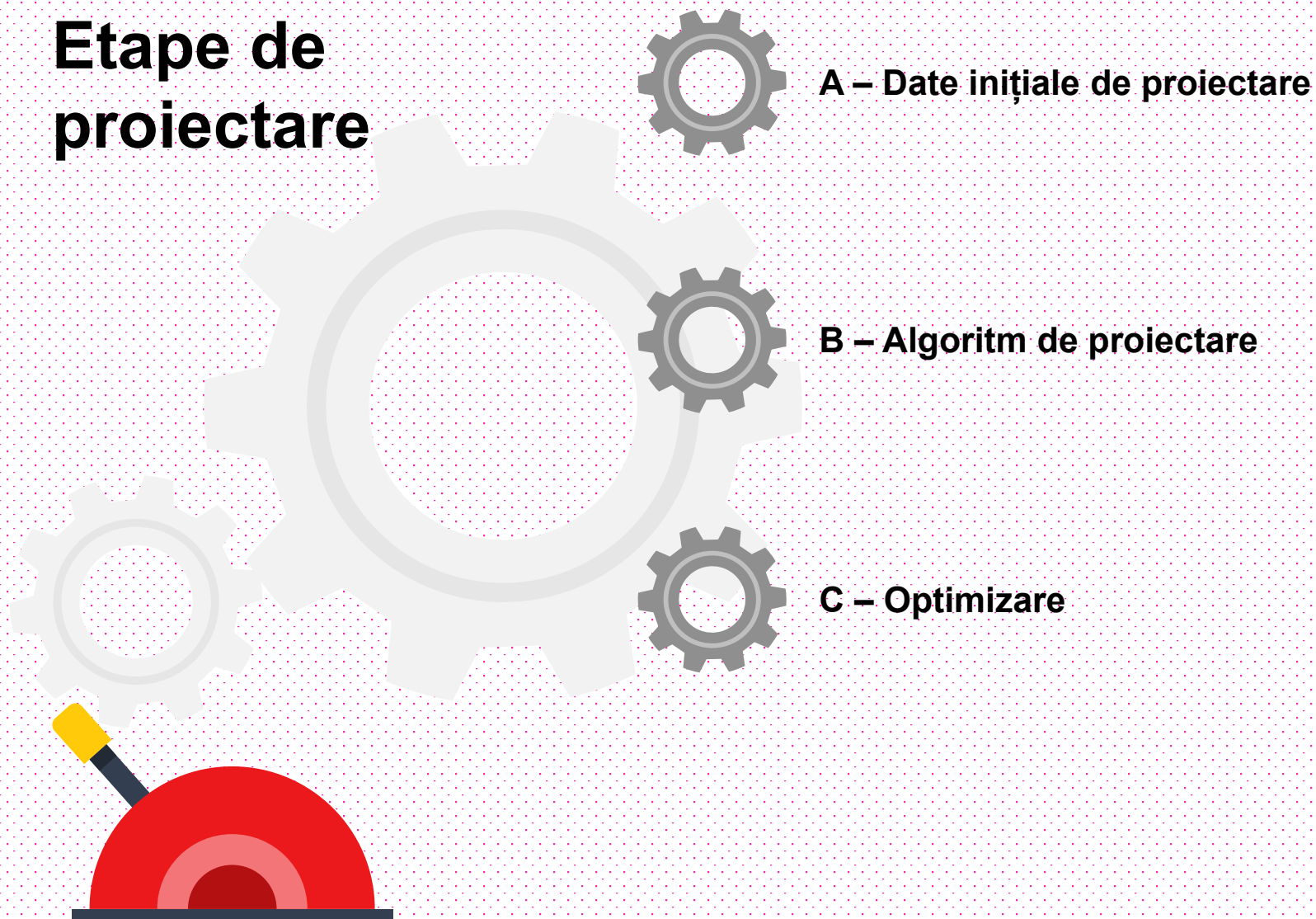




PROIECTAREA MAȘINILOR ELECTRICE

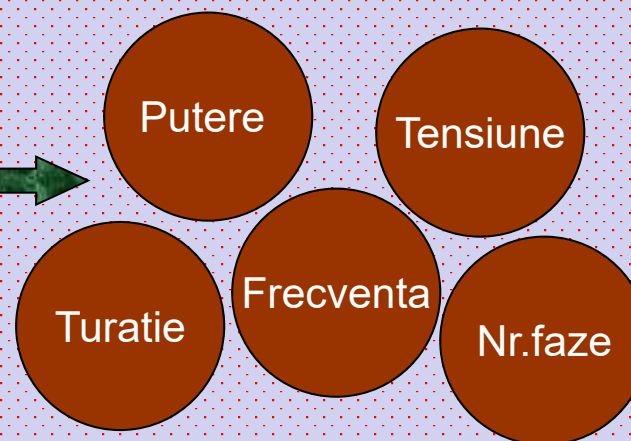


Etape de proiectare



A – Date inițiale de proiectare

**Datele nominale ale mașinii
(cele înscrise pe plăcuța indicatoare)**



☞ **Condiții impuse de sistemul în care este integrată mașina electrică**

☞ **Mărimi standardizate**

B – Algoritm de proiectare

- I. Determinare dimensiuni geometrice principale
- II. Calculul parametrilor electrici
- III. Determinarea caracteristicilor de functionare
- IV. Calculul pierderilor si determinarea curbei randamentului
- V. Dimensionarea accesoriilor mecanice (ax, lagăre, carcasa, cuva, piese de îmbinare)
- VI. Calculul ventilației si al răcirii
- VII. Determinarea solicitărilor termice



STATOR

Diametru interior, D

Lungime, l_i

Solicitări electromagnetice, A și B_δ

Număr de creștături, Z_1

Înfășurare, w_1 , n_c

Profil și dimensiuni creștătură

Intrefier

Lățime, δ

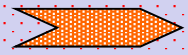
ROTOR

Număr de creștături, Z_2

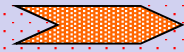
Înfășurare, w_2 , n_c sau s.c.

Profil și dimensiuni creștătură





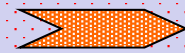
Rezistențe



Inductanțe utile și de dispersie



Permeanțe



Reactanțe



- a. – caracteristica magnetica la gol si curentul de excitație (MCC + MS)
- curentul de magnetizare (MAS + TR)**

- b. – caracteristici de funcționare la gol , sarcina, externe si de reglaj (generatoare)**

- c. – caracteristici mecanice si de reglaj (motoare)**



C – Optimizare

Conform Wikipedia

Optimizarea reprezintă activitatea de *selectare*, din mulțimea soluțiilor posibile unei probleme, a acelei soluții care este cea mai bună în raport cu un criteriu predefinit. Această definiție implică existența următoarelor componente:

- a. O problemă tehnică a cărei soluție poate fi determinată printr-un calculul matematic;
- b. Existența mai multor soluții pentru aceeași problemă;
- c. Un criteriu de selectare a soluției optime.

Cuvinte cheie

Funcția obiectiv : reprezintă expresia matematică a criteriului de optimizare.

Constrângeri : limitări impuse asupra variabilelor de proiectare.

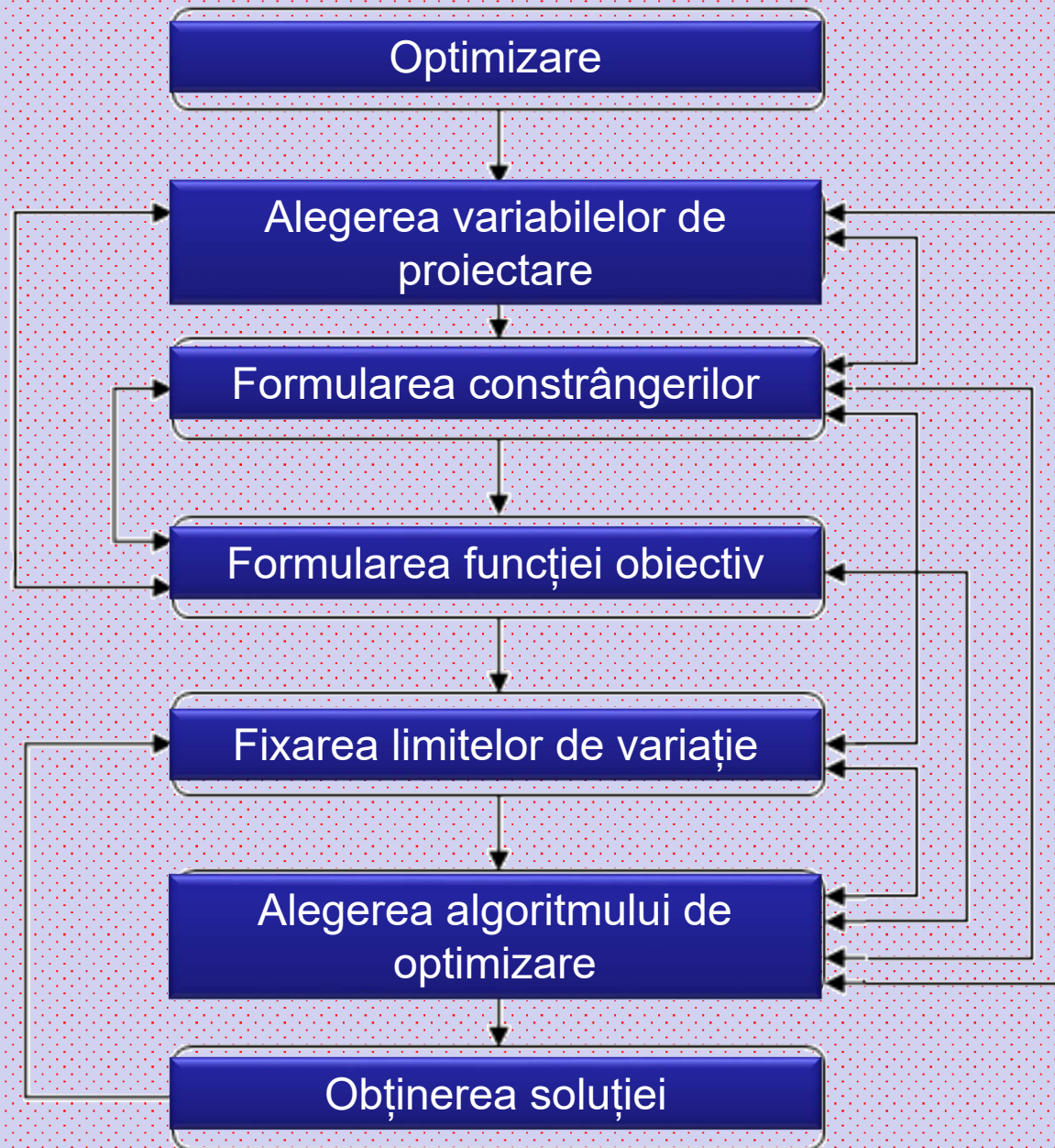


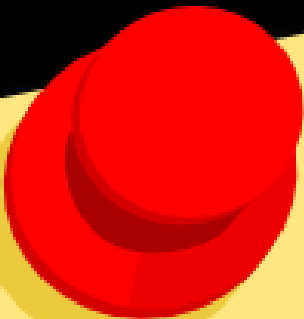
Diagrama logică a unei proceduri de optimizare

Variabile de proiectare: sunt mărimile care, în procesul de proiectare, influențează în cea mai mare măsură soluția finală și care se modifică semnificativ odată cu modificarea diversilor parametri de proiectare.

Constrângerile: reprezintă relații particulare între variabilele de proiectare și alți parametri de proiectare ce satisfac anumite proprietăți fizice sau anumite limitări impuse în mod particular.

Funcția obiectiv: expresia matematică ce caracterizează procesul optimizat.

Fixarea limitelor de variație: fixarea valorilor între care este permisă variația variabilelor și (sau) a parametrilor de proiectare



Introducere in
Metoda Elementului Finit⁽¹⁾



Dep. Elec. Machines

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FEM with FLUX

➤ Ce este metoda elementului finit

➤ Cum lucrează metoda elementului finit

➤ Scurta istorie a dezvoltării metodei

➤ Domenii de aplicație

➤ Pachete de programe comerciale

Fenomene fizice



Ecuatii differentiale



Metode analitice

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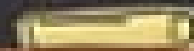
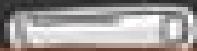
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Metoda
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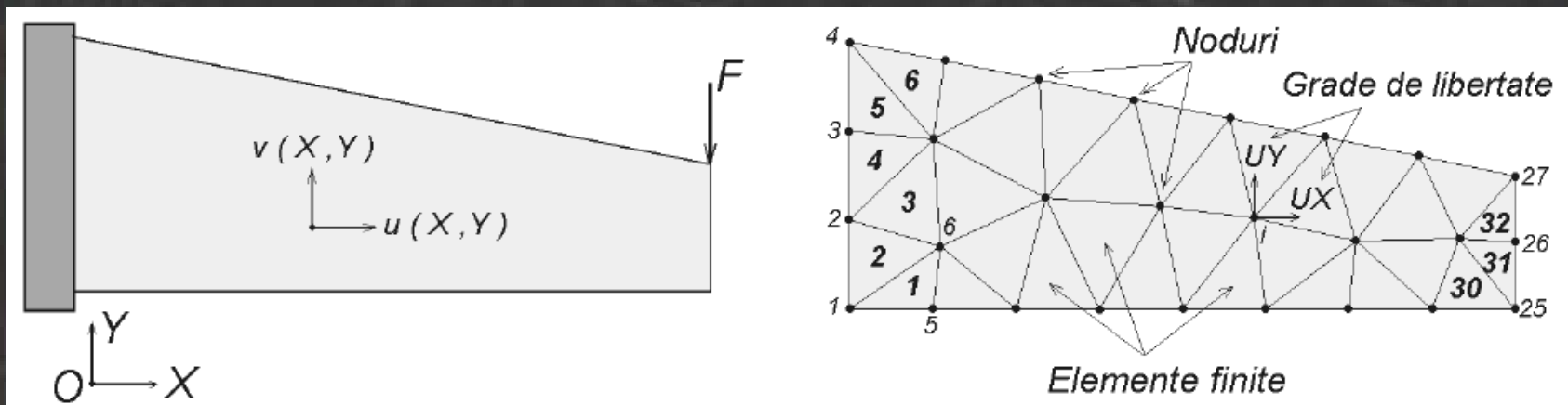
FINITE ELEMENT METHOD – FEM

FINITE ELEMENT ANALYSIS – FEA

- Metoda numerica de calcul
- Obținerea unei soluții aproximative pentru ecuații cu derivate sau derivate parțiale ce sunt înlocuite cu ecuații algebrice

Cum lucreaza metoda elementului finit?

- Divizarea *domeniului de studiu* in subdomenii numite *elemente finite*
- Inlocuirea ecuatiei ce caracterizeaza intraga structura cu ecuatii ce caracterizeaza fiecare element
- Obtinerea solutiei globale pe baza rezultatelor obtinute pentru fiecare element



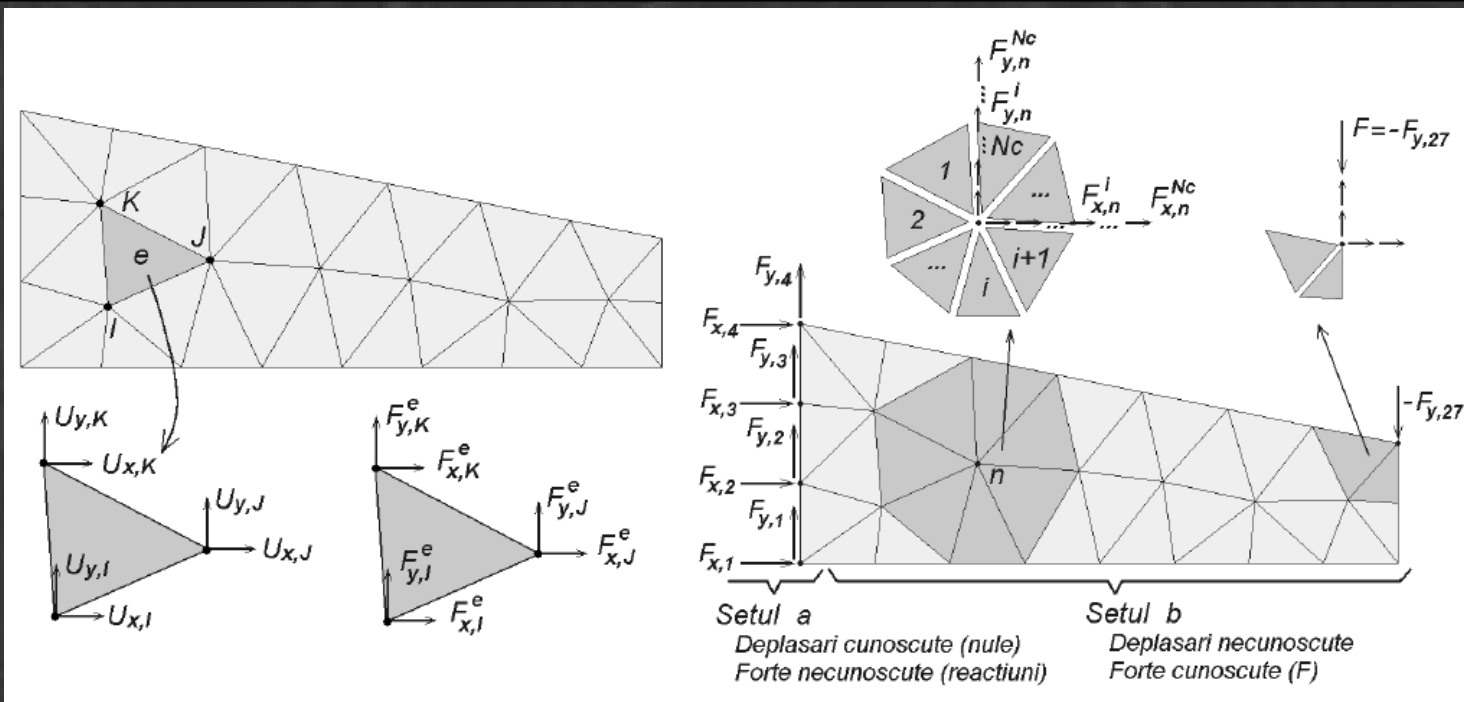
- elemente finite fara suprapuneri
- *noduri* – asigura interactiunea intre elemente (fiecare are 2 grade de libertate)
- frontierele intre elemente – trebuie sa asigure continuitatea

Cum lucreaza metoda elementului finit?

$\{U\} = \{U_{x,1} \quad U_{y,1} \quad U_{x,2} \quad U_{y,2} \dots U_{x,N} \quad U_{y,N}\}^T$ vectorul deplasărilor nodale totale

$\{F\} = \{F_{x,1} \quad F_{y,1} \quad F_{x,2} \quad F_{y,2} \dots F_{x,N} \quad F_{y,N}\}^T$ vectorul forțelor nodale totale

$$\sum_{i=1}^{N_c} F_{x,n}^i = F_{x,n} \quad \sum_{i=1}^{N_c} F_{y,n}^i = F_{y,n} \quad \{F\} = [K] \cdot \{U\}$$



Cum lucreaza metoda elementului finit?

Cauza

**Caract.
material**

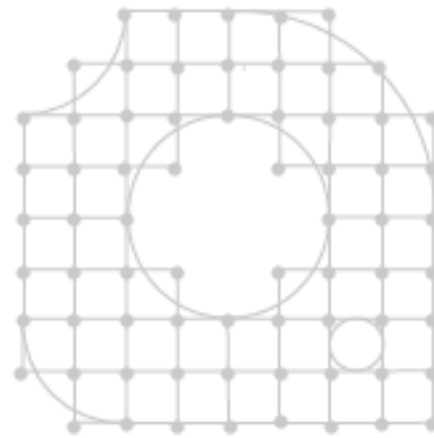
Efect

$$\{F\} = [K] \cdot \{U\}$$

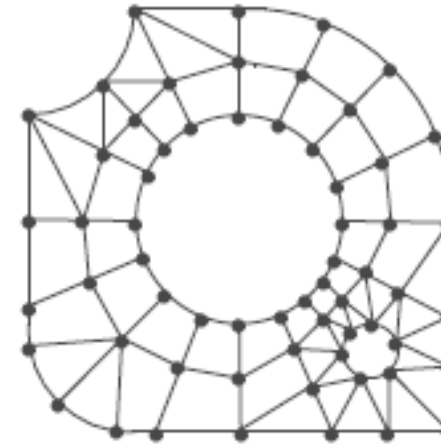
	Cauza {F}	Caracteristici de material [K]	Efect {U}
Deformare elastica	Fora	Modul de elasticitate, rigiditate	Deplasare
Analiza termica	Sursa de caldura	Conductivitate termica	Temperatura
Electromagnetism	Sarcina (electrica sau magnetica)	Permeabilitate magnetica	Potential magnetic



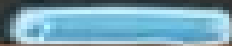
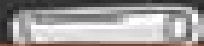
Structura geometrica



Metoda diferentelor finite



Metoda elementelor finite



Metoda diferențelor finite

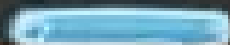
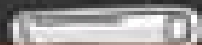
- da o aproximare a ecuației diferențiale IN PUNCTE (pointwise)
- forme simple, sarcini constante, materiale cu proprietăți liniare

Metoda elementelor finite

- da o aproximare a ecuației diferențiale PE PORȚIUNI (piecewise)
- forme complexe, sarcini variabile, materiale cu proprietăți neliniare
- rețeaua acoperă mai bine domeniul de studiu (elemente de tip parabolic)



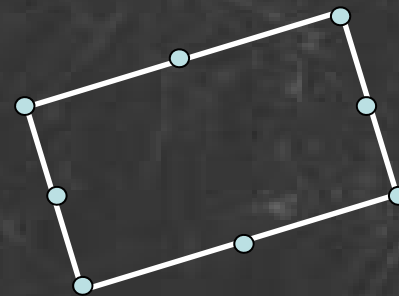
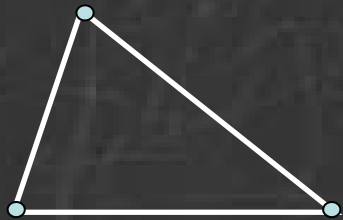
In MEF variația necunoscutei în interiorul elementului este parte a procesului de rezolvare în timp ce în MDF sunt calculate numai valorile nodale



Cum lucreaza metoda elementului finit?

PASUL 1

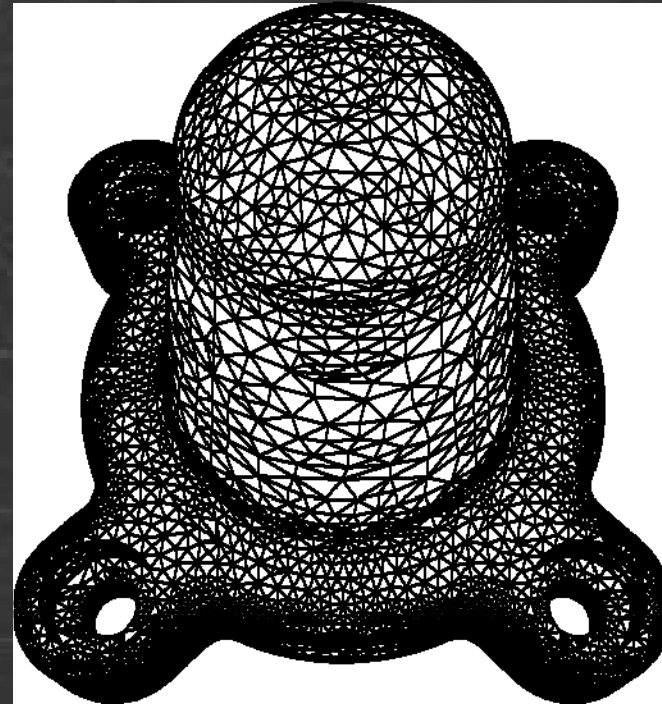
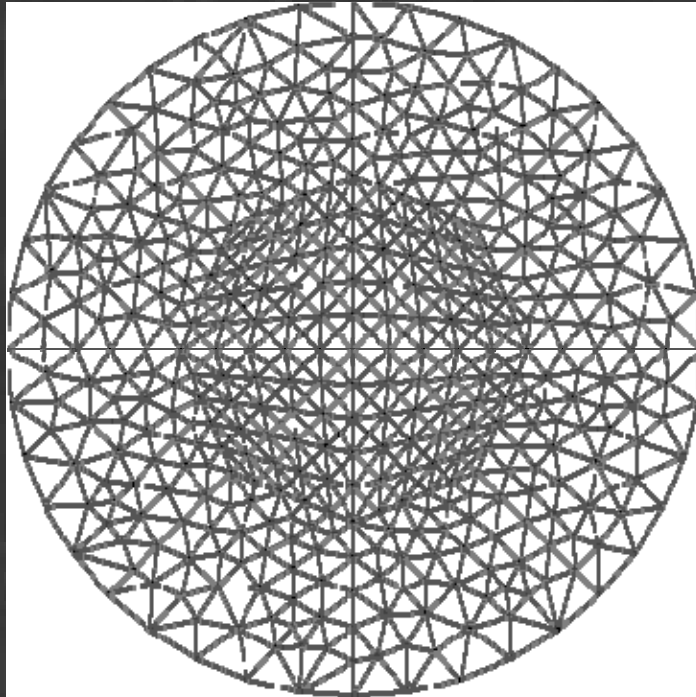
Divizarea domeniului de studiu in elemente finite



Elemente	Liniare	Parabolice	Cubice
Unidimensionale			
Bidimensionale			
Tridimensionale			

Cum lucreaza metoda elementului finit?

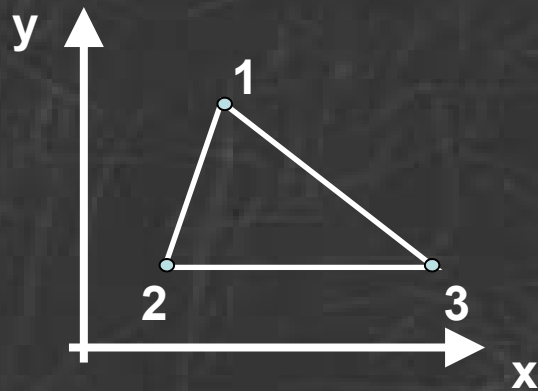
PASUL 1



Cum lucreaza metoda elementului finit?

PASUL 2

Definirea functiei de interpolare (de aproximare)



$$U = a + bx + cy$$

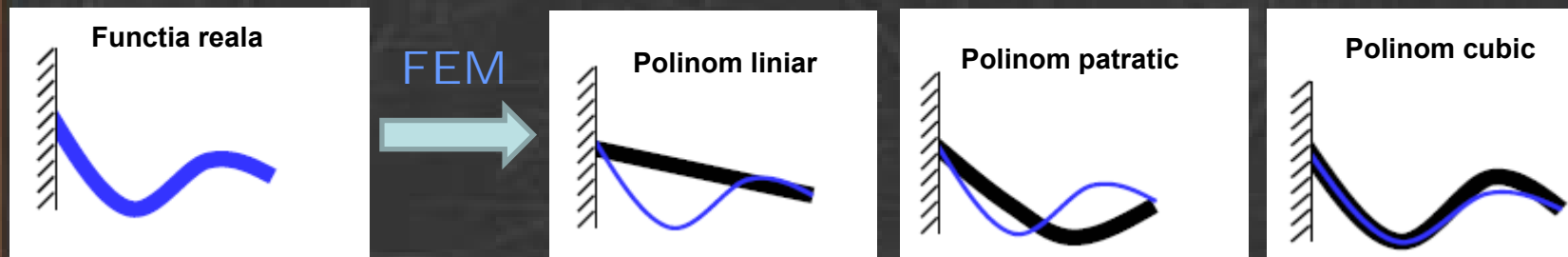
$$\begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix} = \begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

“Modeleaza” variatia necunoscutei in **INTERIORUL** elementului (cel mai adesea este un polinom, uneori serie trigonometrica)

Cum lucreaza metoda elementului finit?

PASUL 2

Definirea functiei de interpolare (de aproximare)



Cum lucreaza metoda elementului finit?

PASUL 3

Stabilirea ecuatiei matriciale ce exprima proprietatile fiecarui element

$$\mathfrak{I} = \iiint_{D_c} f\left(x, y, z, U, \frac{\partial U}{\partial x}, \frac{\partial U}{\partial y}, \frac{\partial U}{\partial z}, \dots\right) dx dy dz + \iint_{\Sigma} g(x, y, z) dS$$

Funcționala – exprimare matematica in forma integrala a energiei potențiale a unui sistem caracterizat de un anumit fenomen




Cum lucreaza metoda elementului finit?

PASUL 3

Metode de rezolvare a funcționalei:

- a. *Metoda directa* (aplicabila numai in cazul problemelor simple)

 - b. *Metoda variatională* –principiul minimizării energiei potențiale a sistemului

 - c. *Metoda reziduurilor ponderate* (metoda Galerkin) – calculează DIRECT ecuațiile fiecărui element finit prin înlocuirea ecuației diferențiale cu un polinom algebric de aproximație dupa care “se lucrează” asupra erorii reziduale
- 

Cum lucreaza metoda elementului finit?

PASUL 3

Metoda variatională – esența metodei consta in faptul ca minimizarea functionalei furnizează modelul diferențial al acestuia, adică ecuația diferențială satisfăcută de mărimea de stare

Minimizarea funcționalei presupune un sistem de ecuații dat de :

$$\frac{\partial \mathcal{J}}{\partial U} = 0$$

care conduce la un sistem algebric liniar de forma:

$$[M_1] = [U] \cdot [M_2]$$

unde M_1 si M_2 sunt matrici complet determinate care depind numai de geometria domeniului de studiu.

Cum lucreaza metoda elementului finit?

PASUL 3

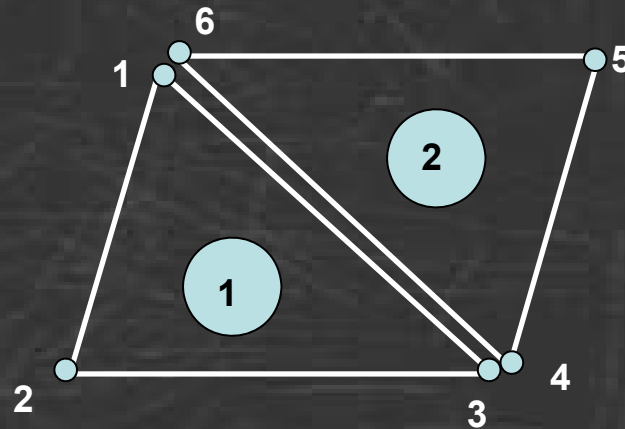
Câmp electromagnetic nestaționar:

$$\mathfrak{S} = \int_{D_c} \left\{ \left(\int_0^E D dE - \int_0^B H dB \right) + (JA - \rho_v V) \right\} dx dy dz$$

Cum lucreaza metoda elementului finit?

PASUL 4

Asamblarea ecuatiilor matriciale individuale intr-un sistem ce descrie proprietatile globale



PASUL 5

Impunerea conditiilor de frontiera

1. *Conditii tip Dirichlet* – se cunoaste si impune valoarea necunoscutei pe frontiera (liniile de camp sunt paralele cu frontiera)
2. *Conditii tip Neumann* – se cunoaste valoarea derivatei necunoscutei pe frontiera (liniile de camp sunt perpendiculare pe frontiera)



Cum lucreaza metoda elementului finit?

PASUL 6

Rezolvarea sistemului de ecuatii – determinarea necunoscutei in noduri



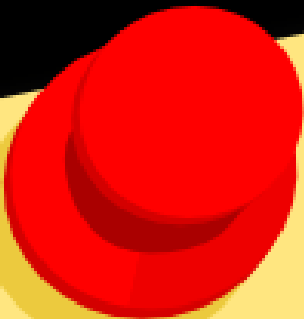


Cum lucreaza metoda elementului finit?

PASUL 7

Rezolvări post procesare pentru determinarea
marimilor asociate





Introducere in
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- Ce este metoda elementului finit
- Cum lucreaza metoda elementului finit
- Scurta istorie a dezvoltarii metodei
- Domenii de aplicatie
- Pachete de programe comerciale



Scurta istorie

1942-1943

Alexander Hrennikoff si *Richard Courant* publică primele lucrări in care apare noțiunea de divizare a unui domeniu continuu in sub-domenii discrete, denumite generic ELEMENTE

Hrennikoff - folosește o structura tip grilaj

Richard Courant folosește pentru prima data elemente triunghiulare si principiul energiei potențiale minime (studiul problemei St. Venant)



1959

J. Greenstadt

– divizează domeniul de studii in subdomenii INTERCONECTATE si descrie o procedura prin care funcția necunoscuta este echivalata cu o serie de funcții ce caracterizează fiecare “celula”.

- alocă funcții de aproximare pentru fiecare celula si folosind *principiul variațional* “leagă” ecuațiile tuturor celulelor.



Scurta istorie

1960

Ray Clough

– introduce termenul de “element finit”.





Scurta istorie

1965

Zienkiewicz si Cheung

– arata ca MEF este aplicabila TUTUROR problemelor de camp ce pot fi modelate intr-o forma variationala

- in 1967 publica prima carte consacrata MEF






Scurta istorie

anii 1960

Specialisti NASA impreuna cu compania MSC Software (MacNeal & Schwendler Corp.) dezvoltă PRIMUL cod sursă **NASTRAN** pentru analiza structurală a aeronavelor






Scurta istorie

dupa 1970

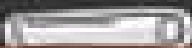
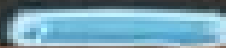

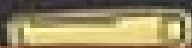

Apar primele pachete comerciale de software dedicat analizei MEF : Abaqus, Adina, Ansys, Sap



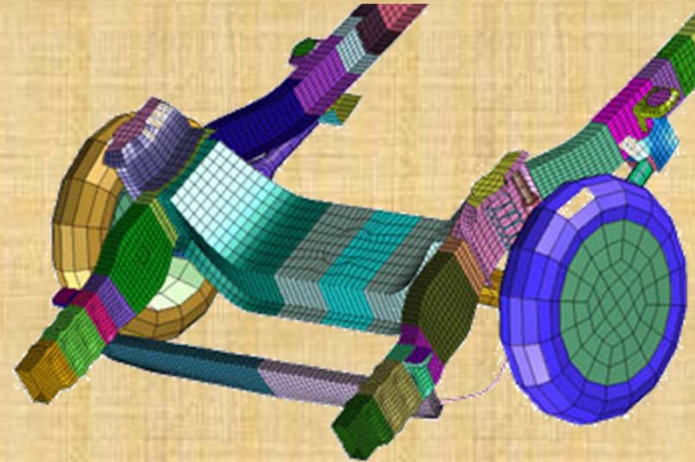
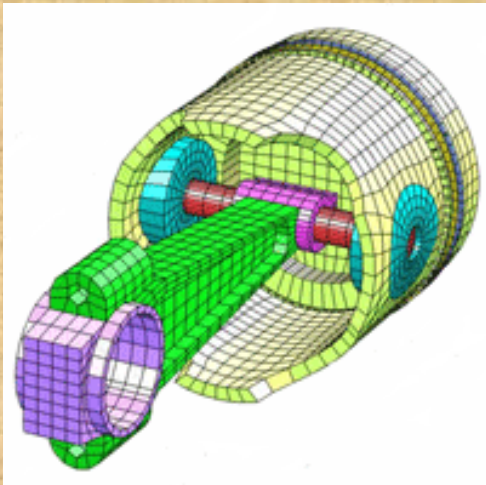
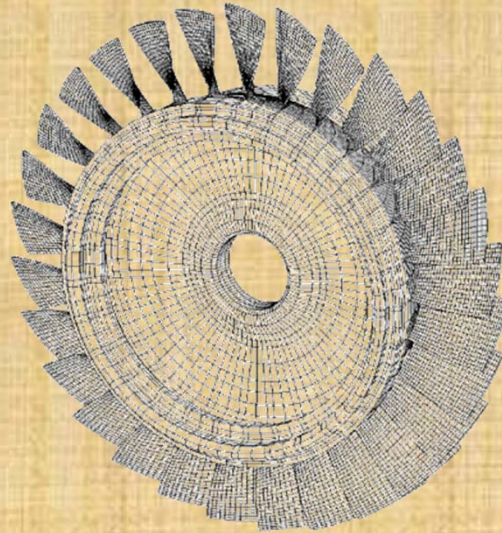
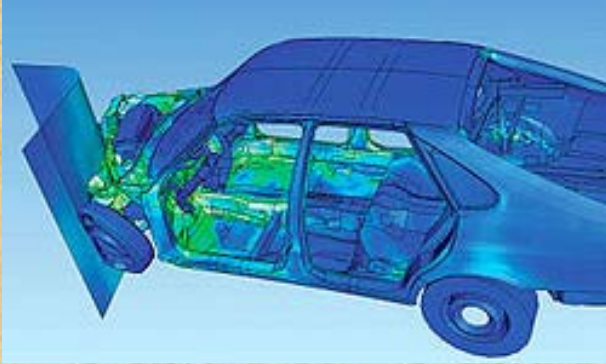
I. Analize de tip structural

- ✓ Calculul sollicitarilor in diverse structuri, bare cu zabrele, etc
 - ✓ Calculul deformatiilor in diverse structuri
 - ✓ Calculul vibratiilor
- 

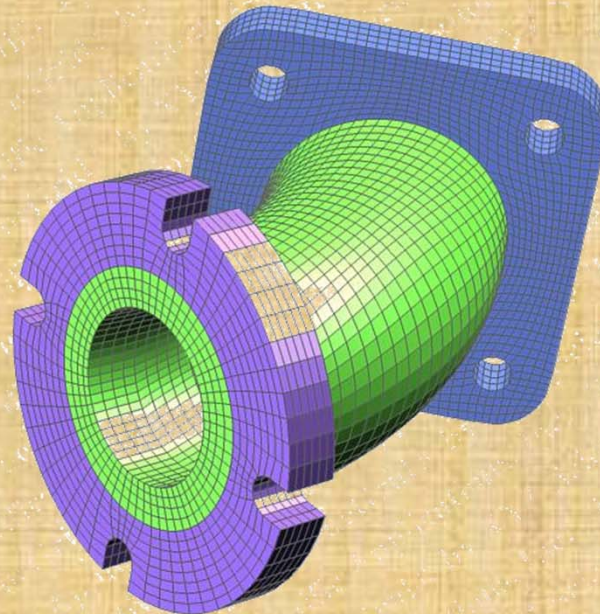
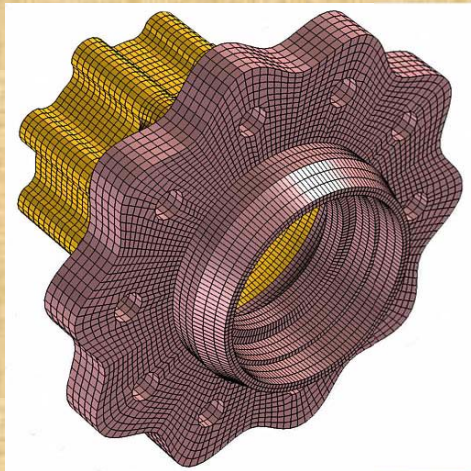
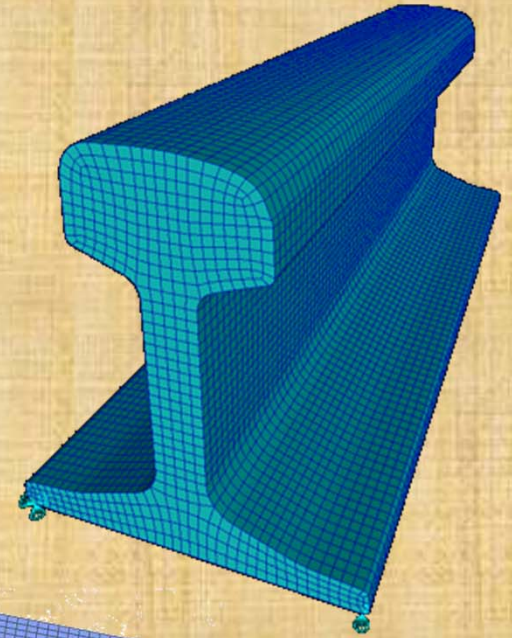
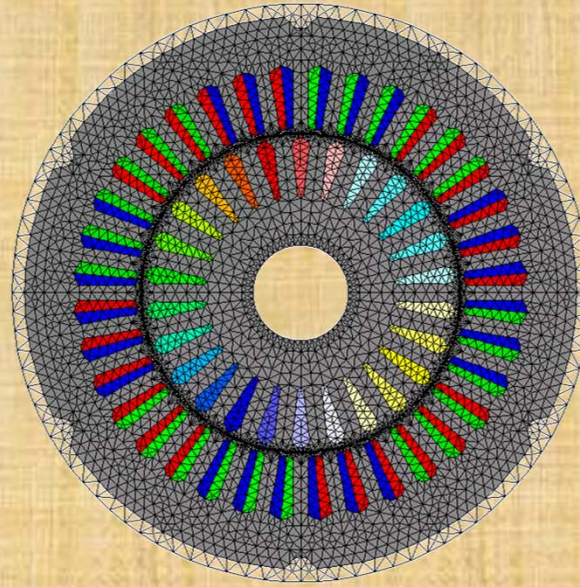
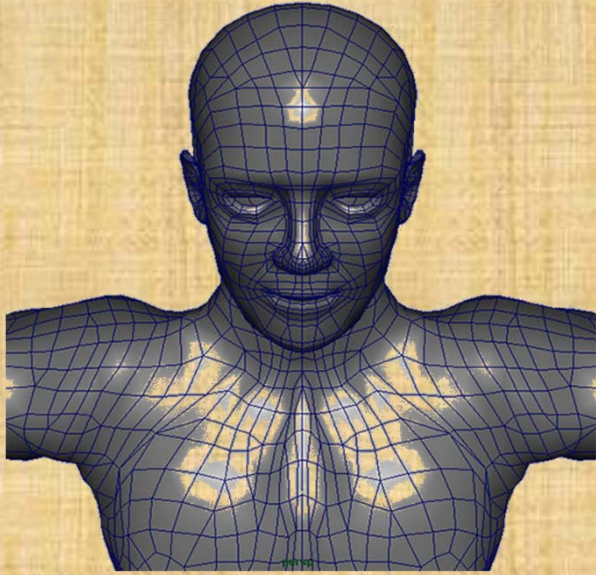
II. Analize non-structurale

- ✓ Transfer de caldura
 - ✓ Curgerea fluidelor inclusiv infiltratii in medii poroase
 - ✓ Calculul campului electric si magnetic
- 
- 
- 
- 
- 

Aplicatii

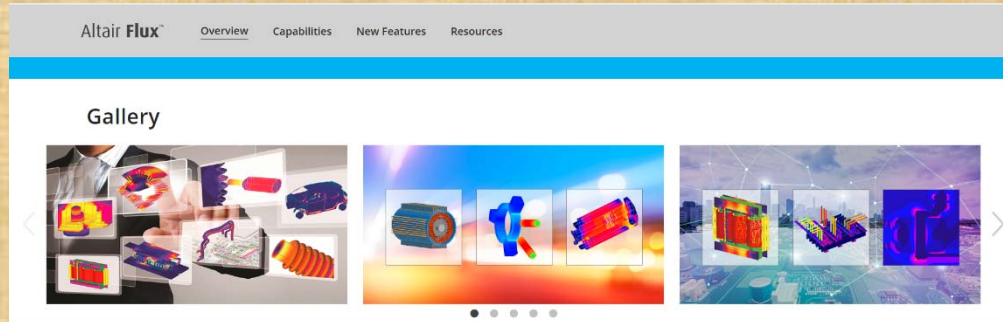


Aplicatii



Pachete de programe comerciale

<https://www.altair.com/flux/>



❖ electromagnetism

❖ campuri termice

❖ probleme cuplate

Versiunea 12.2



Flux 12 New features

Enter your 3D geometry more efficiently



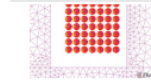
- A new powerful 3D geometric parametric modeler
- 3D modeling constructs remains fully parameterized
- Improved import process
- Get access to all the import formats in one package

Compute 3D Eddy-currents faster



- Reduced solving time with symmetries and periodicities in 3D
- Fully automatic magnetic and electric loop cuts set-up
- Improved solver algorithms and linear solvers upgrades
- Numerous speed-ups in the software operation

Evaluate Joule losses accurately



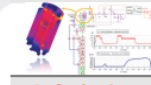
- Fast evaluation of AC skin & proximity losses in coils in 2D and 3D
- Innovative auto-adaptive mesh of the skin depth in 2D Steady state AC

Go multiphysics: consider now vibration and thermal aspects in your design



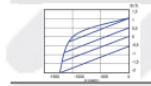
- Flux coupled to external CFD software (Star-CCM+® or Fluent)
- Extended magneto-thermal capabilities in Flux
- An improved connection to LMS Virtual.Lab and MSC Nastran for vibro-acoustics

Connect to system simulation



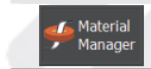
- Fast table extraction towards system level tools
- Co-simulation with LMS Imagine.Lab Amesim™ for linear actuation

Go further in your electric machine design



- Accounting for demagnetization of permanent magnets
- Automated generation of Efficiency maps
- Hysteresis current control of 3-phase electric machines

Access to more material modeling capabilities



- More than 450 materials now available in the database
- New non-linear electric behaviour of materials

... and discover the performance of Flux 12 through a complete set of new examples!

Pachete de programe comerciale



- www.ansys.com

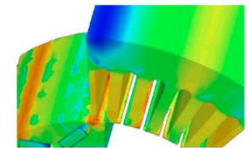
- ❖ mecanica structurala;
- ❖ dinamica fluidelor;
- ❖ electromagnetism;
- ❖ fenomene optice;
- ❖ multiphysics

ANSYS Maxwell

ANSYS Maxwell is the industry-leading electromagnetic field simulation software for the design and analysis of electric motors, actuators, sensors, transformers and other electromagnetic and electromechanical devices. With Maxwell, you can precisely characterize the nonlinear, transient motion of electromechanical components and their effects on the drive circuit and control system design. By leveraging Maxwell's advanced electromagnetic field solvers and seamlessly linking them to the integrated circuit and systems simulation technology, you can understand the performance of electromechanical systems long before building a prototype in hardware. This virtual electromagnetic lab gives

Electric Motors

Engineers who design electric machines need simulation tools that can be employed for quick, accurate product development. By employing finite element methods early in the design process, they can accelerate development and achieve higher machine efficiencies using less material, which reduces costs. Furthermore, to achieve an optimal motor design demands a full multiphysics analysis workflow. Assuming that the machine will remain in the intended operating range can lead to poor design choices, redesign late in the development cycle or product failure. ANSYS' electric machine design flow provides a complete virtual prototyping laboratory for machine design and development.



Examples

<p>Electronic Machine Design Methodology: A Revolutionary Approach - White Paper</p>	<p>Electrical Drive Modeling through a Multiphysics System Simulation Approach - Application Brief</p>	<p>AC Motor Drive Using Cosimulation - Application Brief</p>	<p>Multiphysics Design Flow for Electric Motors</p>	<p>Advanced Design of Electric Machines Using the ANSYS Electric Machine Design Toolkit - Application Brief</p>
--	--	--	---	---

Pachete de programe comerciale



- www.infolytica.com

❖ camp electromagnetic

❖ analiza termala

MOTORSOLVE PRODUCT FAMILY

<p>MotorSolve BLDC</p> <p>Sync. Reluctance; IPM; Surface Mounted; Bread-loaf; Spoke; Inset; Motor or Generator mode.</p>	<p>MotorSolve IM</p> <p>Interior and exterior rotors; All standard bar shapes; All standard wound configurations.</p>	<p>MotorSolve DCM</p> <p>Brushes; PMDC; Series; Shunt; Universal; more.</p>
<p>MotorSolve SRM</p> <p>Templates for both interior and exterior types.</p>	<p>MotorSolve Thermal</p> <p>Simulates the impact of heating and applied cooling on the motor's</p>	

infolytica corporation

PRODUCTS ▾ APPLICATIONS ▾ SUPPORT ▾ COMPANY ▾ NEWS ▾ CONTACT US

OVERVIEW
 FEATURES
 OPTIONS
 BROCHURE
 VIDEO DEMO
 TRIAL EDITION
 CONTACT SALES

MagNet v7
 2D/3D ELECTROMAGNETIC FIELD SIMULATION SOFTWARE
 PREDICTING PERFORMANCE FOR BETTER DESIGN

MagNet v7 2D/3D simulation software for electromagnetic fields lets you rapidly model and predict the performance of any electromagnetic or electromechanical device:

- Electric Motors/Generators
- Magnetic Levitation
- Transformers
- Actuators
- Sensors/NDT
- Induction Heating
- Loudspeakers
- Magnetic Recording Heads
- MRI
- Transcranial Magnetic Simulations

WORKFLOW

```

  graph TD
    A[SAT, DXF, Prof., IGS, STEP, Inventor, CATIA] -- Import model --> B[PSM Simulink VHDL, AMS]
    B --> C[System Simulations]
    C --> D[Optimization]
    D --> E[OptiNet Automated Design Optimization]
    D --> F[ThermNet Thermal Simulations]
  
```

MagNet's solution approach is based on the highly accurate finite element method for simulating static, frequency dependent or time varying electromagnetic fields.

Efficiency is key, that's why MagNet includes many automated features which reduce the time to perform each design cycle.

RECENT IMPROVEMENTS

- Improved nonlinear surface impedance approximation
- Easily model laminations with the perfect electric insulators boundary condition
- Predict the surface force density on a component
- Trajectory Evaluator v3 released which supports MagNet 3D time-harmonic and transient
- Multicore mesh generator, solvers, and post processor for even

Pachete de programe comerciale

Opensource

Finite Element Method Magnetics: HomePage - Mozilla Firefox

File Edit View History Bookmarks Yahoo! Tools Help

http://www.femm.info/wiki/HomePage

Most Visited Getting Started Latest Headlines Customize Links Free Hotmail Windows Marketplace Windows Media Windows

WEB SEARCH

BieneSoft explore with YAHOO! SEARCH Search

YouTube Amazon eBay Options

Finite Element Method Magnetics: H...

Finite Element Method Magnetics : HomePage

HomePage :: Search :: PageIndex :: RecentChanges :: Login/Register

- Download
- Documentation
- FAQ
- Linux Support
- Examples
- User Contributions
- Miscellaneous
- Related Links
- Author

Page History :: 2009-08-05 23:35:04 XML :: Owner: DavidMeeker :: Search:

Pachete de programe comerciale

COSMOS[®]

- www.solidworks.com



- ❖ mecanica structurala
- ❖ dinamica fluidelor
- ❖ analiza termica
- ❖ analiza vibratiilor
- ❖ probleme cuplate

The screenshot shows the SolidWorks website's 'SIMULATION' page. At the top, there is a navigation bar with links for PRODUCTS, INDUSTRIES, HOW TO BUY, SUPPORT, COMMUNITY, RESOURCE CENTER, and CUSTOMERS. Below this is a search bar and contact information for US & CANADA (800-693-9000 and +1-781-810-5011). The main heading is 'SIMULATION' with a sub-headline: 'Raise the quality of your products, and reduce costs for live prototypes and testing by easily subjecting your designs to real-world conditions.' Below this is a large image of a mechanical part with a color-coded stress simulation. A navigation menu includes Packages, Solutions, Capabilities, Downloads, Academia, What's New, Videos, and Matrices. The main content area is titled 'SOLIDWORKS Simulation Solutions' and describes the benefits of simulation. It includes a 'Get a Simulation Product Demo' link and a 'Featured Solutions' section with nine categories: Structural Analysis, Thermal Analysis, HVAC Analysis, Fatigue Analysis, Vibration Analysis, Structural Optimization, Motion Analysis, Fluid Flow Analysis, and Electronic Cooling. Each category has a brief description of what it involves.

SOLIDWORKS Simulation Solutions
Enable every designer and engineer to simulate and analyze design performance with fast, easy-to-use SOLIDWORKS Simulation CAD-embedded analysis solutions. You can quickly and easily employ advanced simulation techniques to optimize performance while you design with capabilities that cut down on costly prototypes, eliminate rework and delays, and save you time and development costs.

Quickly and easily employ advanced simulation techniques to optimize performance while you design

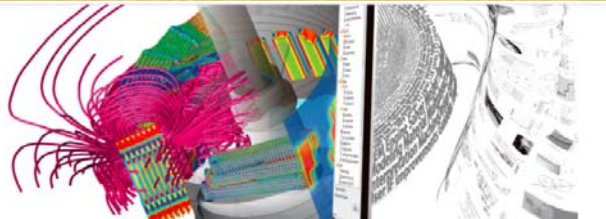
» Get a Simulation Product Demo

Featured Solutions

- Structural Analysis**
Validate product performance and safety factors using finite element analysis (FEA) to perform structural simulation.
- Thermal Analysis**
Calculate temperatures and heat transfer within and between components.
- HVAC Analysis**
Optimize heating, ventilating, and air conditioning systems quickly and easily.
- Fatigue Analysis**
Predict component fatigue failures by examining repeated or random load cycles.
- Vibration Analysis**
Examine how vibrating or unstable modes can shorten equipment life to eliminate failures.
- Structural Optimization**
Optimize a design to meet defined strength-to-weight, frequency, or stiffness performance.
- Motion Analysis**
Evaluate mechanical performance through operational movements using rigid body motion analysis.
- Fluid Flow Analysis**
Simulate fluid (either liquid or gas) passing through or around an object and investigate the impact to improve product performance.
- Electronic Cooling**
Optimize heat dissipation and the selection of electronic devices.

Pachete de programe comerciale

JMAG-Designer



- www.jmag-international.com

❖ baza de date cu modele de masini electrice

❖ camp electromagnetic

❖ camp termic

❖ analiza vibroacustica

❖ multiphysics

JMAG-Express

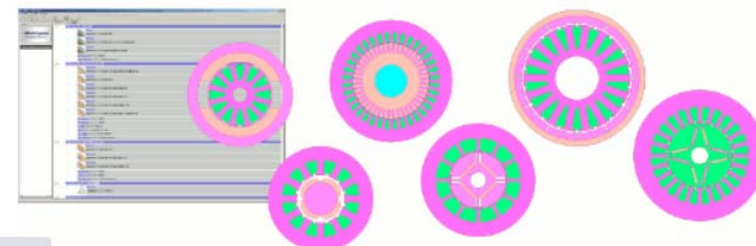
JMAG-Express is a tool to support motor design.

Template based, conceptual design can be carried out with it. It can also easily link with JMAG-Designer for detailed design. It can export motor models (JMAG-RT models) at any stage, allowing SILS and HILS to be done.

Functions

▶ Freely define geometry templates

- Templates for PMSMs, induction motors, brush motors, and universal motors have all been prepared.
- You can add geometries created in JMAG-Designer as templates.
- Use JMAG-Designer for brush motors and universal motors.



Pachete de programe comerciale



- www.comsol.com

❖ mecanica structurala

❖ acustica

❖ inginerie chimica

❖ transfer de caldura

❖ electromagnetism

❖ antene

❖ plasma

❖ stiinta pamantului (geofizica, curgerea fluidelor pe si sub pamant, magnetism terestru)

❖ specializat in analize multiphysics

COMSOL Multiphysics®						
COMSOL Server™						
ELECTRICAL	MECHANICAL	FLUID	CHEMICAL	MULTIPURPOSE	INTERFACING	
AC/DC Module	Heat Transfer Module	CFD Module	Chemical Reaction Engineering Module	Optimization Module	LiveLink™ for MATLAB®	LiveLink™ for Excel®
RF Module	Structural Mechanics Module	Mixer Module	Batteries & Fuel Cells Module	Material Library	CAD Import Module	Design Module
Wave Optics Module	Nonlinear Structural Materials Module	Microfluidics Module	Electrodeposition Module	Particle Tracing Module	ECAD Import Module	LiveLink™ for SOLIDWORKS®
Ray Optics Module	Geomechanics Module	Subsurface Flow Module	Corrosion Module		LiveLink™ for Inventor®	LiveLink™ for AutoCAD®
MEMS Module	Fatigue Module	Pipe Flow Module	Electrochemistry Module		LiveLink™ for Revit®	LiveLink™ for PTC® Creo® Parametric™
Plasma Module	Multibody Dynamics Module	Molecular Flow Module			LiveLink™ for PTC® Pro/ENGINEER®	LiveLink™ for Solid Edge®
Semiconductor Module	Acoustics Module				File Import for CATIA® V5	

Pachete de programe comerciale



- www.mscsoftware.com

- ❖ mecanica structurala
- ❖ acustica
- ❖ analiza termica
- ❖ transfer de caldura
- ❖ zgomot, vibratii
- ❖ dinamica rotatiei
- ❖ specializat in analize multiphysics

The screenshot shows the MSC Software website with the following elements:

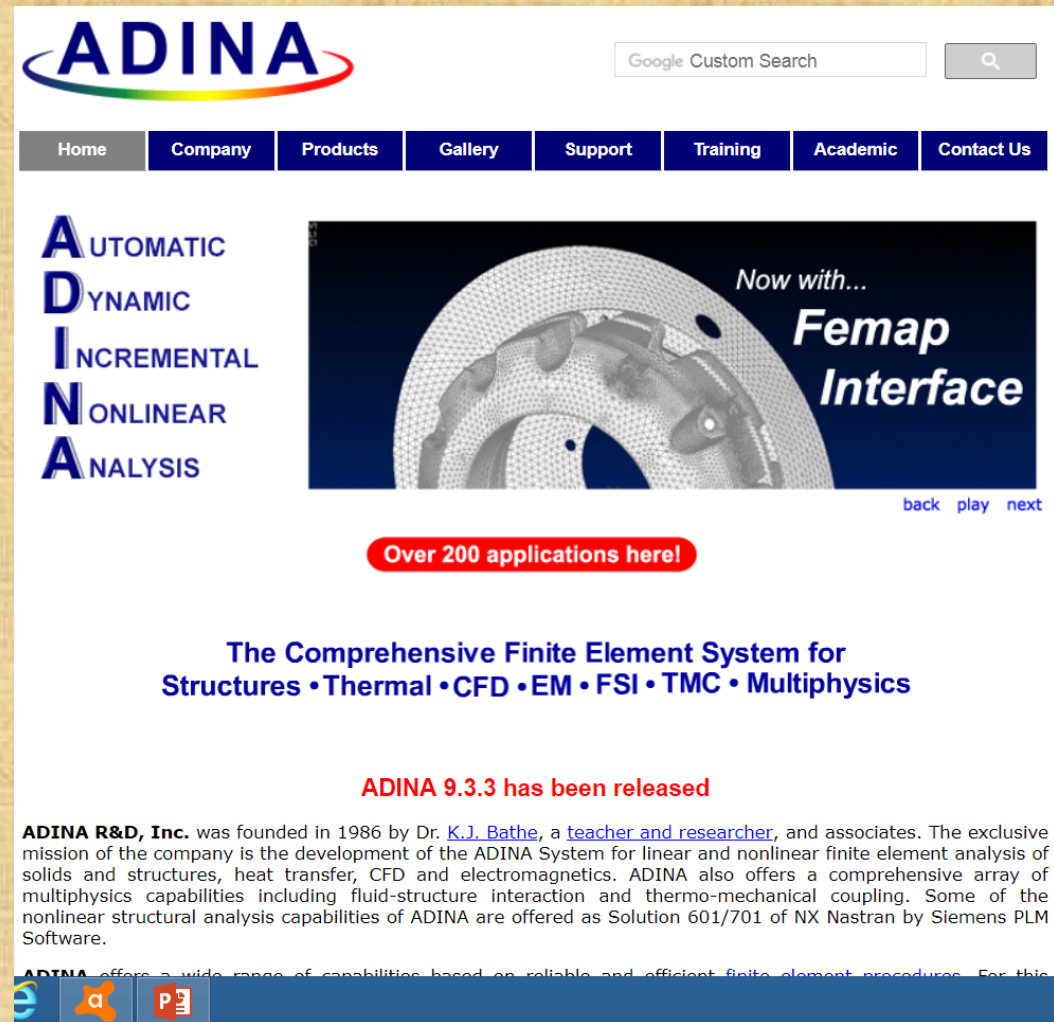
- Header:** MSC Software logo, tagline "Simulating Reality, Delivering Certainty", phone number "+1 855 672 7638", "Sign In", "Contact Us", a location dropdown set to "Americas", and a search bar.
- Navigation Menu:** SOLUTIONS, PRODUCTS, SERVICES & TRAINING, PARTNERS, ACADEMIA, RESOURCES, ABOUT US, SUPPORT.
- Dropdown Menu:** A menu is open under "PRODUCTS" showing two columns: "Applications" (Acoustics, Composites, Crash & Safety, Design Optimization, Fatigue and Durability, Multibody Dynamics, Multidiscipline, Noise & Vibration, Nonlinear Analysis, Process Automation, Rotor Dynamics, SPDM, Structural Analysis, Systems & Controls, Thermal Analysis) and "Industries" (Aerospace, Automotive, Consumer Products, Defense, Electronics, Energy, Heavy Equipment, Machinery, Medical, Motorsports, Packaging, Rail, Shipbuilding).
- Main Content:**
 - Share this page:** A button to share the page.
 - Contact Us:** A prominent red button.
 - Teach with Adams®:** A section promoting educational use, featuring an image of a computer monitor and a blue car model. Text includes: "Prepare future engineering professionals for success." and a "Learn How" button.
 - University Newsletters:** A section titled "University Newsletters" with a quote from Prof. Dan Negrut, Maschinenbau Professor at the University of Wisconsin. The quote reads: "I am very happy with the benefits my students & I drive from using Adams in our coursework and research. MSC has been very willing to work with me to help me achieve my goals for incorporating simulation into our engineering curriculum." Below the quote is a "Learn How" button.
 - Academia Offer:** A section titled "Academia Offer" describing university software bundles. It states: "Our academia software offerings are intentionally simple yet scalable, targeted yet flexible – with similar products bundled together to help maximize your simulation capability while minimizing your cost and administrative work. Each of our 3 university software bundles is network-licensed via a consistent set of 'User Packs' designed to meet each university customer's specific objective:"
- Footer/Bottom Section:**
 - Resources:** A link to "see all" resources.
 - Academic Bundles:** A list of bundles: "Academic Software FEA Bundle Datasheet" and "Academic Software Motion Bundle Datasheet".

Pachete de programe comerciale

ADINA

- www.adina.com

- ❖ mecanica structurala
- ❖ dinamica fluidelor
- ❖ analiza termica
- ❖ transfer de caldura
- ❖ analize multiphysics (interactiune fluid-structura; analiza termo-mecanica)



ADINA

Google Custom Search

Home Company Products Gallery Support Training Academic Contact Us

AUTOMATIC
DYNAMIC
INCREMENTAL
NONLINEAR
ANALYSIS

Now with...
Femap Interface

back play next

Over 200 applications here!

**The Comprehensive Finite Element System for
Structures • Thermal • CFD • EM • FSI • TMC • Multiphysics**

ADINA 9.3.3 has been released

ADINA R&D, Inc. was founded in 1986 by Dr. [K.J. Bathe](#), a [teacher and researcher](#), and associates. The exclusive mission of the company is the development of the ADINA System for linear and nonlinear finite element analysis of solids and structures, heat transfer, CFD and electromagnetics. ADINA also offers a comprehensive array of multiphysics capabilities including fluid-structure interaction and thermo-mechanical coupling. Some of the nonlinear structural analysis capabilities of ADINA are offered as Solution 601/701 of NX Nastran by Siemens PLM Software.

ADINA offers a wide range of capabilities based on reliable and efficient finite element procedures. For this

I. Pachete de programe de uz general



- Pot rezolva mai multe tipuri de probleme
- Li se pot adauga module pentru alte tipuri de probleme
- Nu cer cunostinte speciale de hardware sau programare software

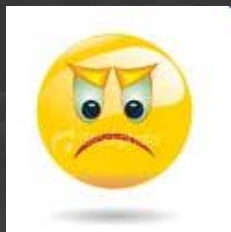


- Costul initial de dezvoltare este mare
- Sunt mai putin eficiente iar unele module pot fi de prisos
- Nu exista acces la algoritmul de programare (eventuale erori sau nevoi de modificare pot fi facute numai de catre firma producatoare)

II. Pachete de programe specializate



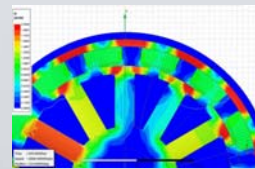
- Programele sunt mici si cu costuri de dezvoltare reduse
- Nu necesita computere puternice
- Sunt eficiente fiind dedicate rezolvarii unui singur tip de problema



- Pot rezolva un singur tip de problema
- Mai multe probleme.....mai multe programe

Principii fundamentale in Metoda Elementului Finit

Scurt rezumat



1

Metoda Elementului Finit (MEF) este o *metoda numerica* ce furnizeaza *solutii aproximative* pentru *ecuatii cu derivate sau derivate partiale* ce descriu fenomene fizice

2

Esența metodei constă în transformarea **domeniului continuu** într-o sumă de **domenii discrete** numite *elemente finite*.

Cu cât numărul de elemente este mai mare



prima aproximare

cu atât soluția obținută este mai exactă

3

În interiorul elementelor acționează *funcția de interpolare*, care este o funcție polinomială ce înlocuiește ecuația diferențială care modelează fenomenul fizic (*a doua aproximare*).

Cu cât ordinul funcției polinomiale este mai mare



cu atât soluția obținută este mai exactă

4

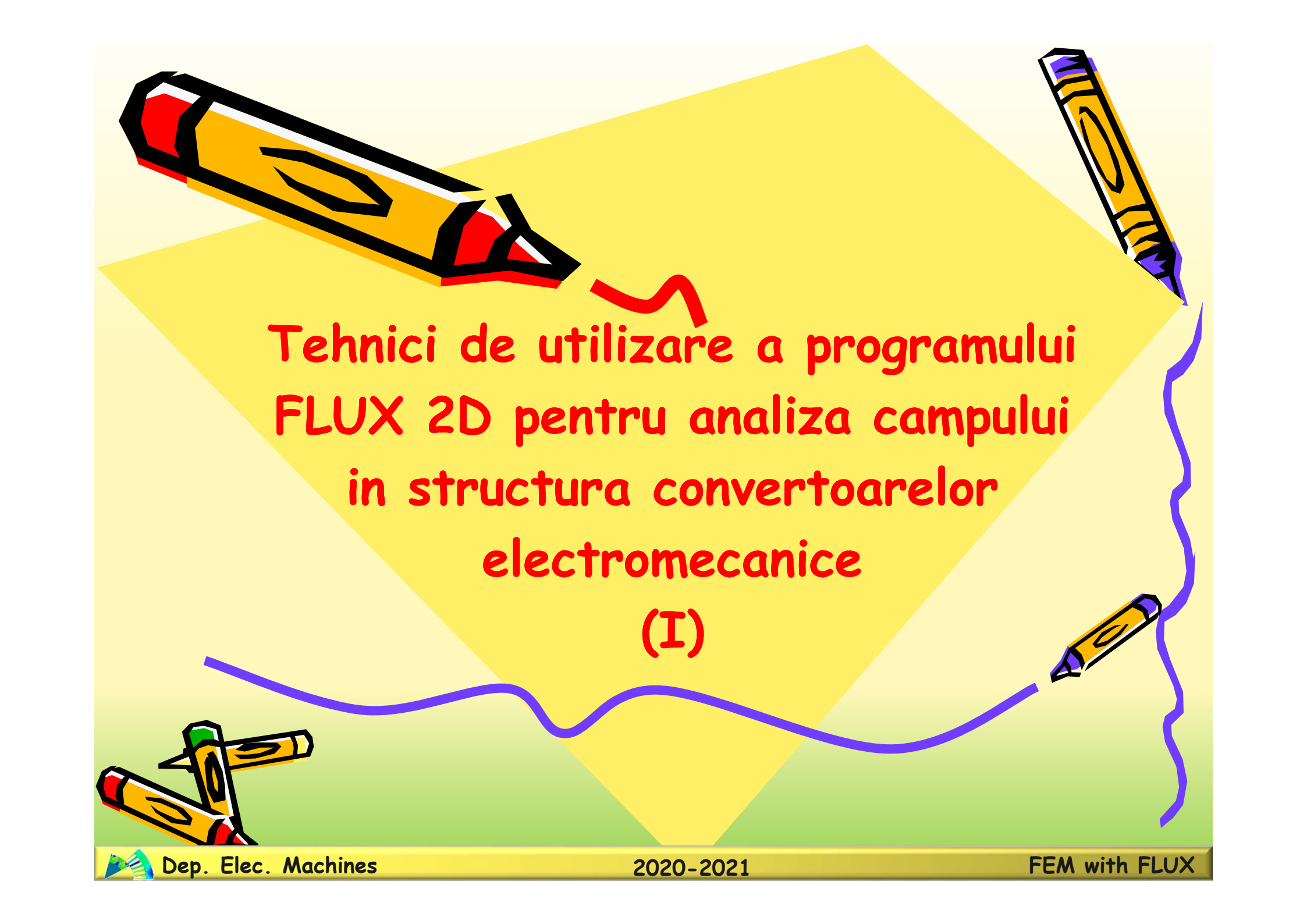
Fixarea condițiilor de frontieră.

- ✓ Condiții Dirichlet
- ✓ Condiții Neumann

5

Asamblarea și rezolvarea ecuațiilor matriciale prin metode de aproximare (a treia aproximare):

- ✓ *Metoda variatională*
- ✓ *Metoda Galerkin*



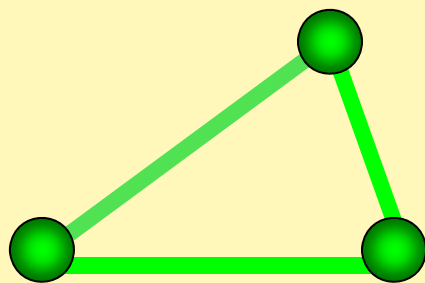
Tehnici de utilizare a programului
FLUX 2D pentru analiza campului
in structura convertoarelor
electromecanice
(I)

Metoda elementului finit

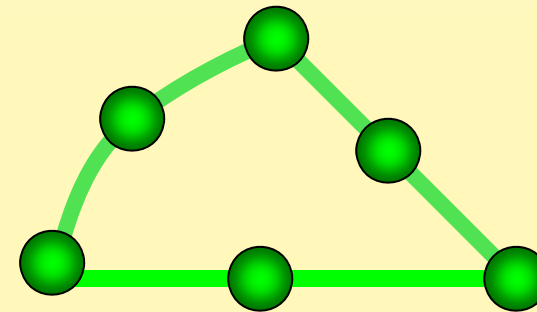
- Metoda numerica de calcul
- Divizarea domeniului de calcul in elemente geometrice simple (elemente finite) caracterizate de prezenta unor puncte speciale (noduri)
- Fiecare element este caracterizat de o functie de stare ce reprezinta o combinatie a valorilor din noduri (functie de interpolare)
- Solutia globala se obtine prin asamblarea ecuatiilor nodale ale elementelor



Element finit triunghiular



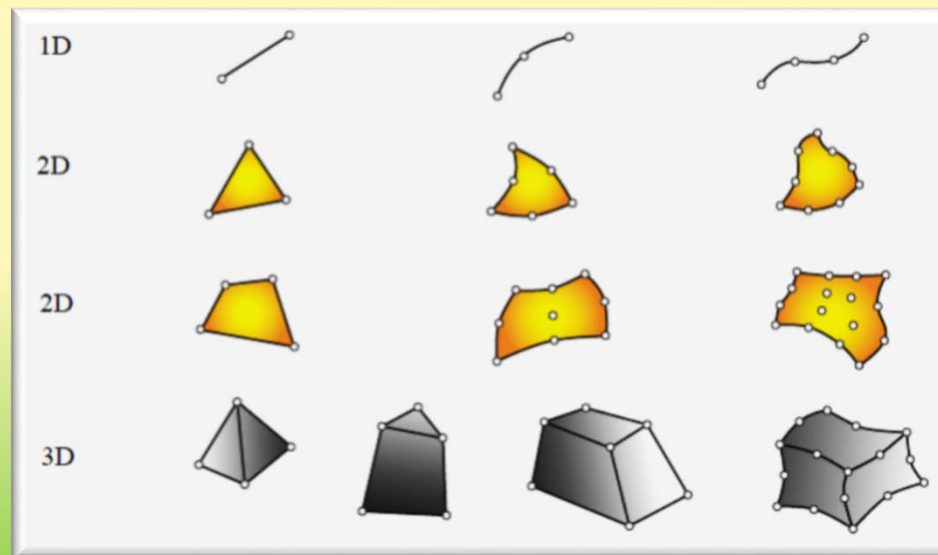
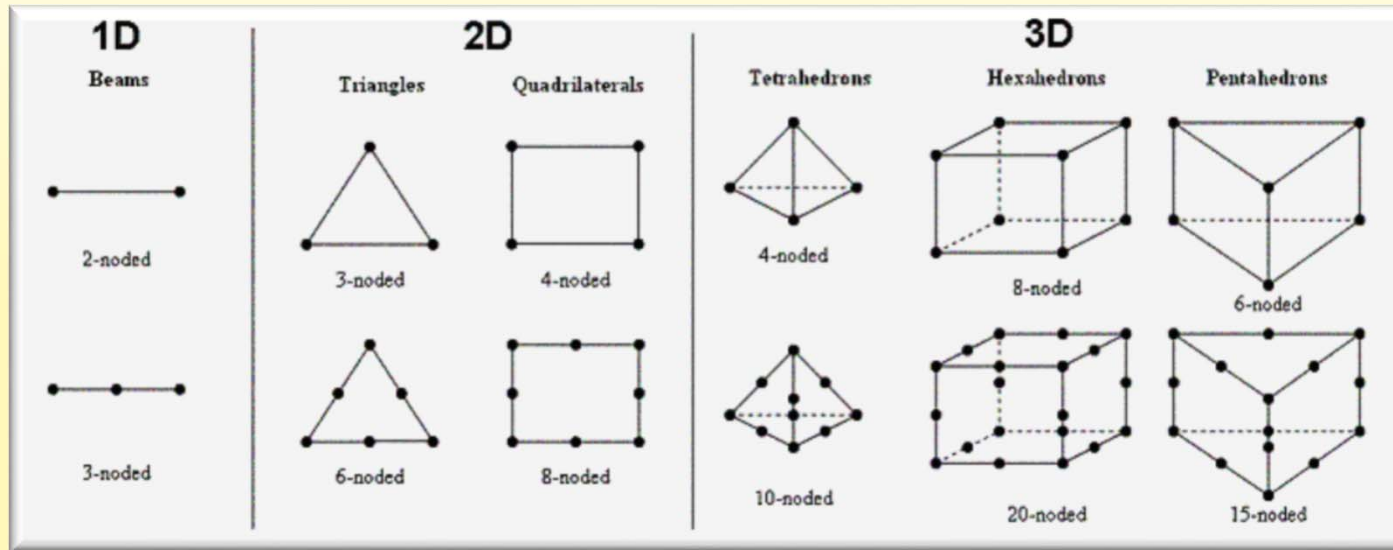
Element finit rectangular
de ordinul I



Element finit parabolic
de ordinul II



Tipuri de elemente finite



Ecuatiile lui Maxwell

$$\left\{ \begin{array}{l} \text{rot } \bar{E} = -\frac{\partial \bar{B}}{\partial t} \quad \text{-- legea inducției electromagnetice} \\ \text{rot } \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t} \quad \text{-- legea circuitului magnetic} \\ \text{div } \bar{D} = \rho_v \quad \text{-- legea fluxului electric} \\ \text{div } \bar{B} = 0 \quad \text{-- legea fluxului magnetic} \end{array} \right.$$

B - inducția magnetică
D - inducția câmpului electric
H - intensitatea câmpului magnetic
E - intensitatea câmpului electric
J - densitate de curent
 ρ_v - densitatea de volum a sarcinii
electrice



Ecuatiile de material

$$\begin{cases} \bar{\mathbf{D}} = \varepsilon_0 \cdot \bar{\mathbf{E}} \\ \bar{\mathbf{B}} = \mu_0 \cdot \bar{\mathbf{H}} \\ \bar{\mathbf{J}} = \tau \cdot \bar{\mathbf{E}} \end{cases}$$

ε_0 - permitivitate electrica
 μ_0 - permeabilitate magnetica
 τ - conductivitate electrica



Marimi de calcul

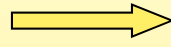
$$\vec{B} = \text{rot } \vec{A} \quad ; \quad A - \text{potential magnetic vector}$$

$$\vec{H} = -\text{grad } P \quad ; \quad P - \text{potential magnetic scalar}$$

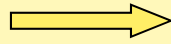
$$\vec{E} + \frac{\delta \vec{A}}{\delta t} = -\text{grad } V \quad ; \quad V - \text{potential electric scalar}$$



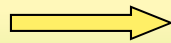
TIPURI DE ANALIZA



MAGNETOSTATICA



MAGNETODINAMICA



TRANZITORIE



Analiza magnetostatica

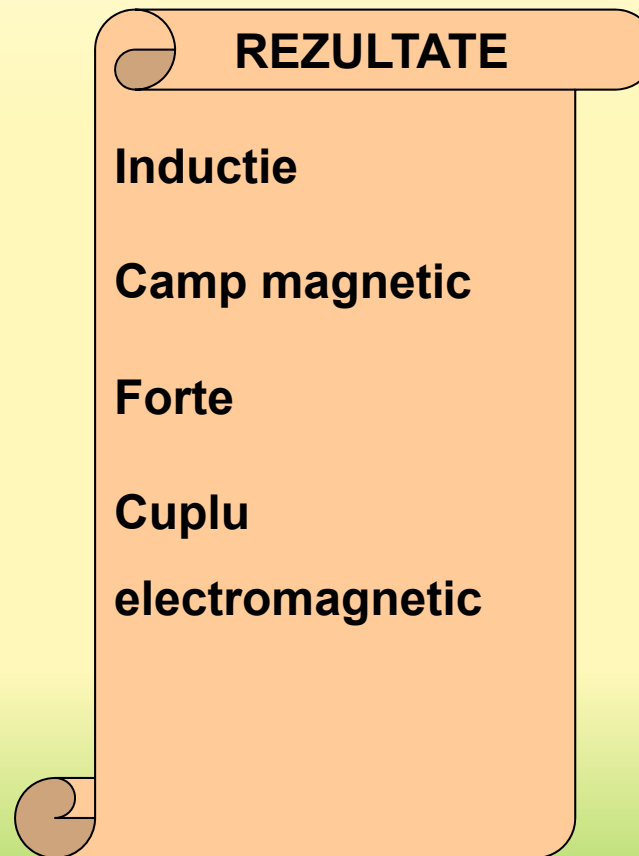
- Curent constant
- Componente geometrice statice
- Lipsa circuitului electric echivalent



MAGNETOSTATICA

Functionare la curent *constant*, corpuri *imobile*

$$\begin{cases} \text{rot } \bar{H} = \bar{J} \\ \text{div } \bar{B} = 0 \end{cases}$$



Analiza magnetodinamica

- Cuplare câmp - circuit
- Mișcare rotativa - liniara



MAGNETODINAMICA

Functionare la curent *sinusoidal*

$$\left\{ \begin{array}{l} \text{rot } \bar{E} = -\frac{\partial \bar{B}}{\partial t} \\ \text{rot } \bar{H} = \bar{J} \\ \text{div } \bar{D} = \rho_v \\ \text{div } \bar{B} = 0 \end{array} \right.$$



REZULTATE

Inductie

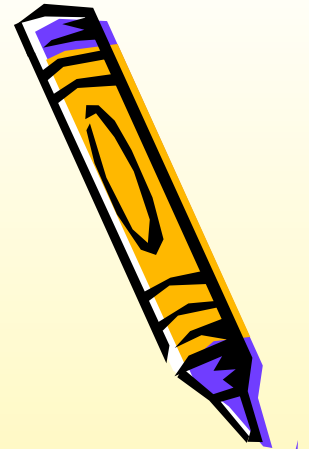
Camp magnetic

Forte

**Cuplu
electromagnetic**

**Curenti, tensiuni,
inductante**

Puteri



Analiza tranzitorie

- Cuplaj câmp - circuit plus ecuații de mișcare
- Variație în timp a mărimilor electrice (tensiuni, curenți, etc.)
- Rezolvare în pași de timp (Time-step resolution)



TRANZITORIU

Functionare la curent *sinusoidal* cu luarea in considerare a starii de miscare

- parametru de calcul: timpul

Inductie

Camp magnetic

Forte

Cuplu
electromagnetic

Curenti, tensiuni,
inductante

Puteri



Analiza magnetostatica

- Alimentare infasurare statorica (pentru un moment fixat al variatiei sinusoidale a sistemului de curenti)
- Absenta reactiei rotorului (situatie echivalenta cu functionarea la sincronism)



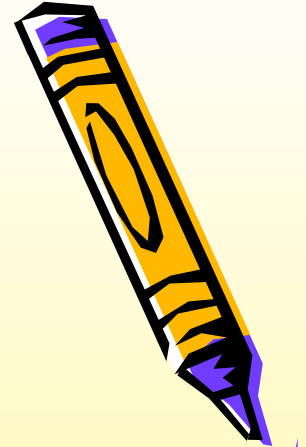
Analiza magnetodinamica

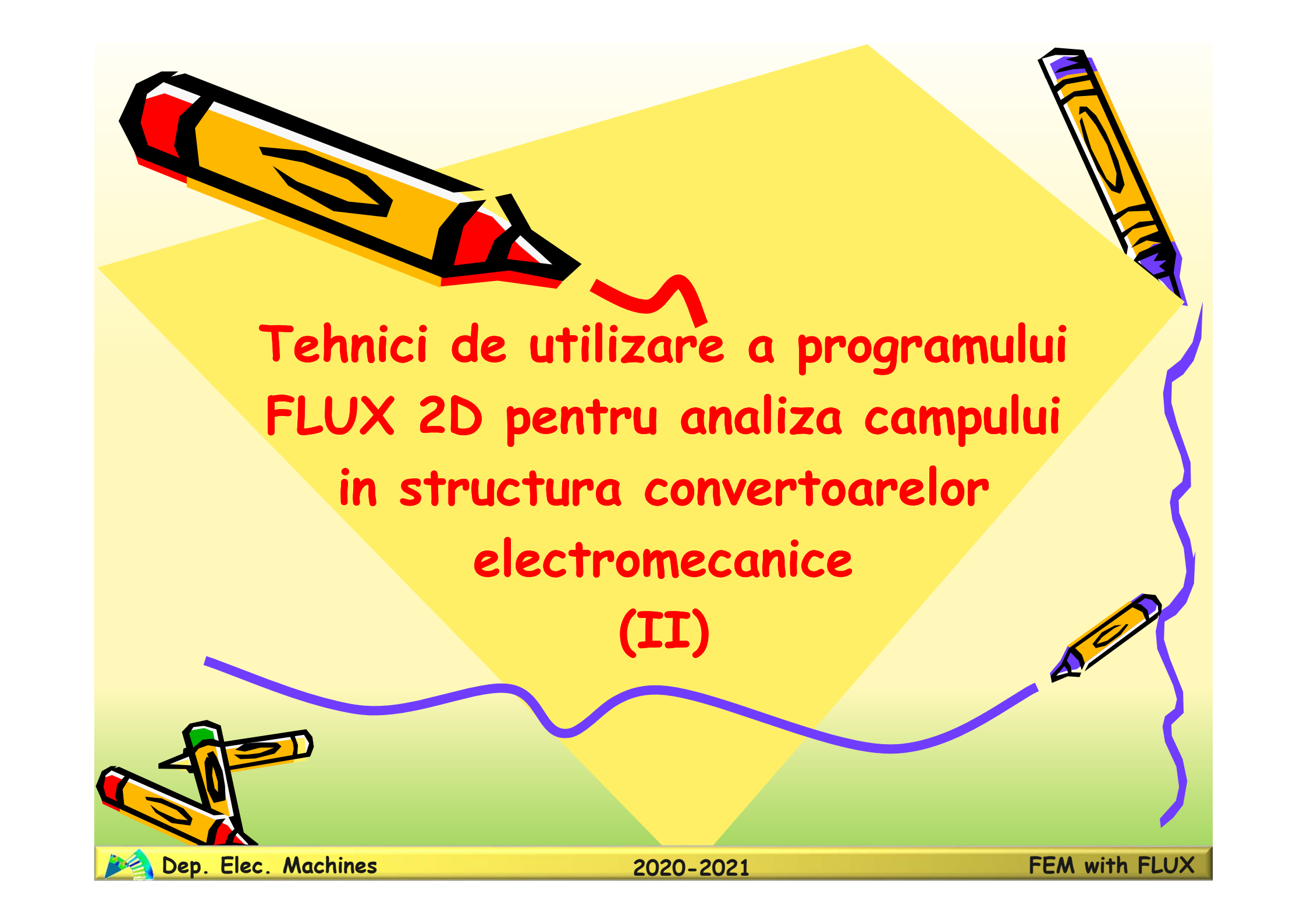
- Cuplarea circuitului magnetic cu circuitul electric al masinii
- Simularea rotirii rotorului la o anumita turatie
- Posibilitatea obtinerii curbei $M=f(s)$ prin rezolvari parametrice la valori impuse ale turatiei



Analiza tranzitorie

- Cuplarea circuitului magnetic cu circuitul electric și ecuațiile de mișcare mecanică ale mașinii
- Modelarea în timp a unui regim tranzitoriu (pornire, frânare)
- Vizualizarea variației mărimilor electrice (tensiuni, curenți)





Tehnici de utilizare a programului
FLUX 2D pentru analiza campului
in structura convertoarelor
electromecanice
(II)

Etape de analiza

I.

PRE-PROCESARE

II.

REZOLVARE

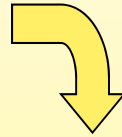
III.

POST-PROCESARE

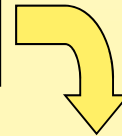


Pre-procesare

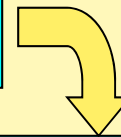
Definirea domeniului de studiu



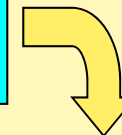
Constructia geometriei



Divizarea domeniului in elemente finite de studiu



Alocarea proprietatilor de material si a conditiilor de frontiera

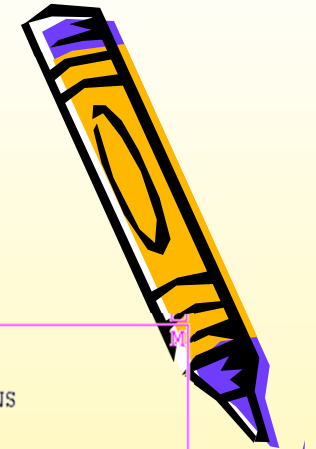
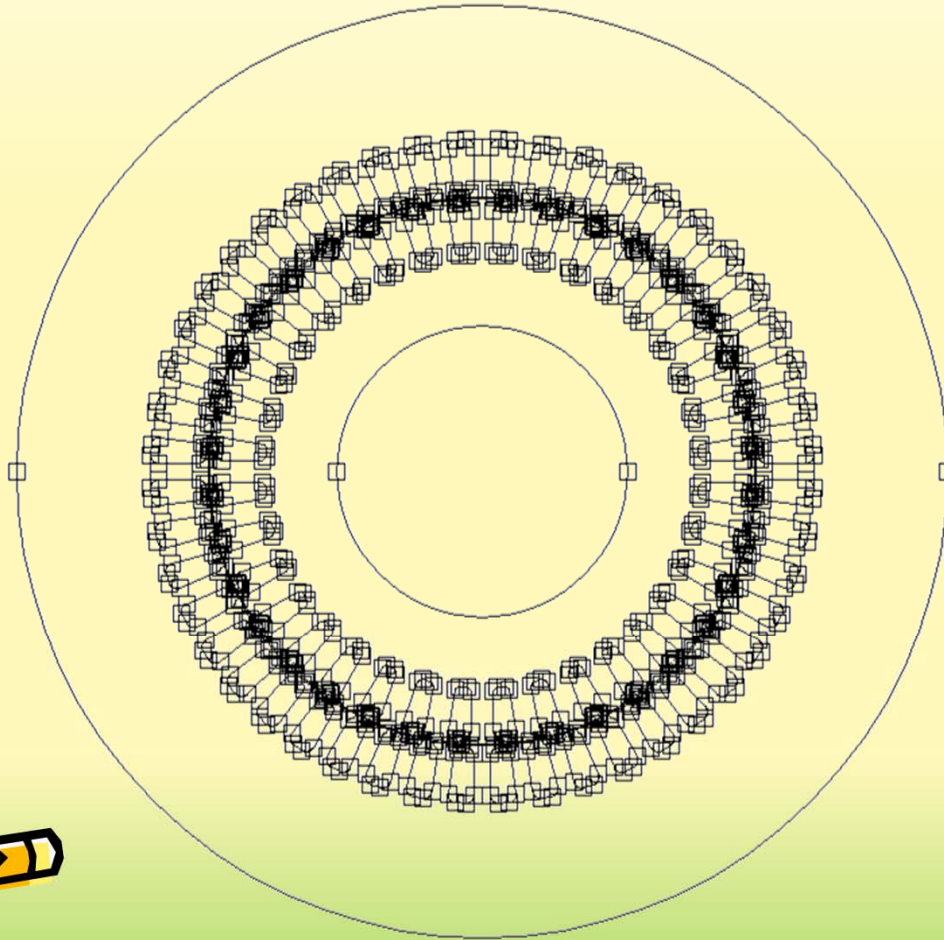


Constituirea circuitului electric



Constructia geometriei

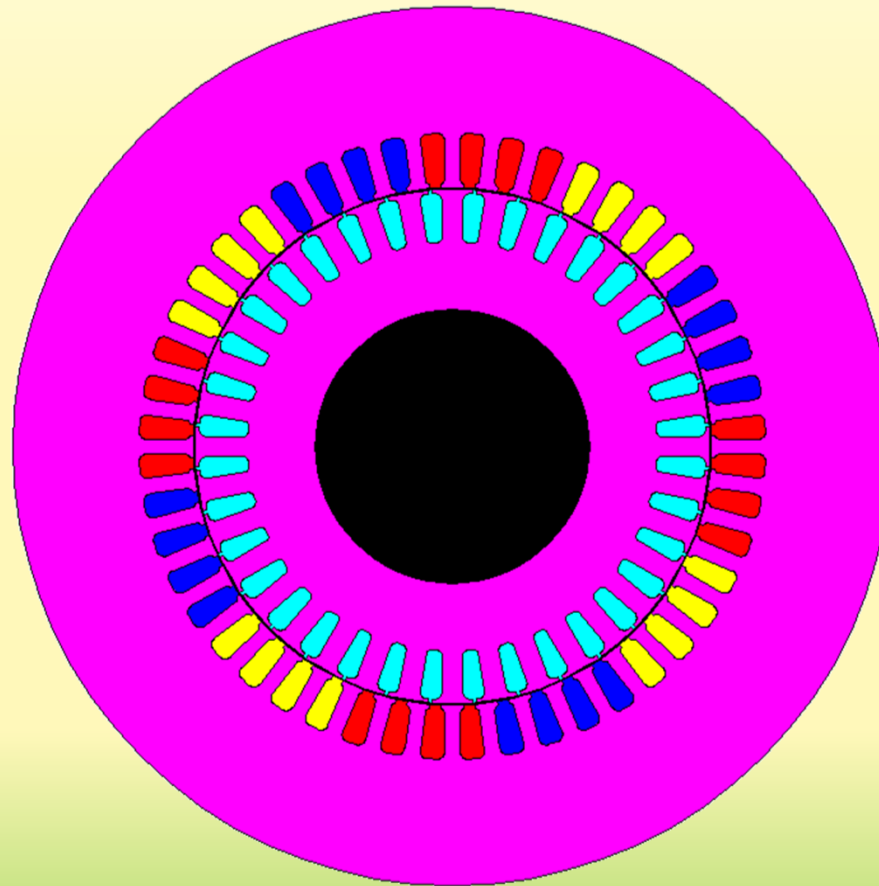
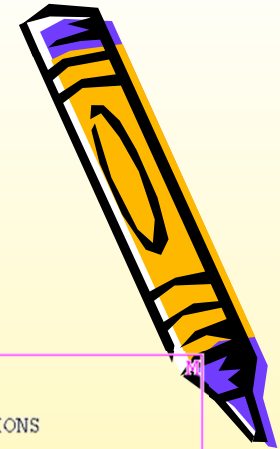
puncte, linii



- ?
OPTIONS
 - Quit
 - Zoom
 - Reset
 - Move
-
- 1 Restore
 - 2 Save
 - 3 Parameters
 - 4 Points
 - 5 Lines
 - 6 Regions
 - 7 Mesh generator



Constructia geometriei suprafete



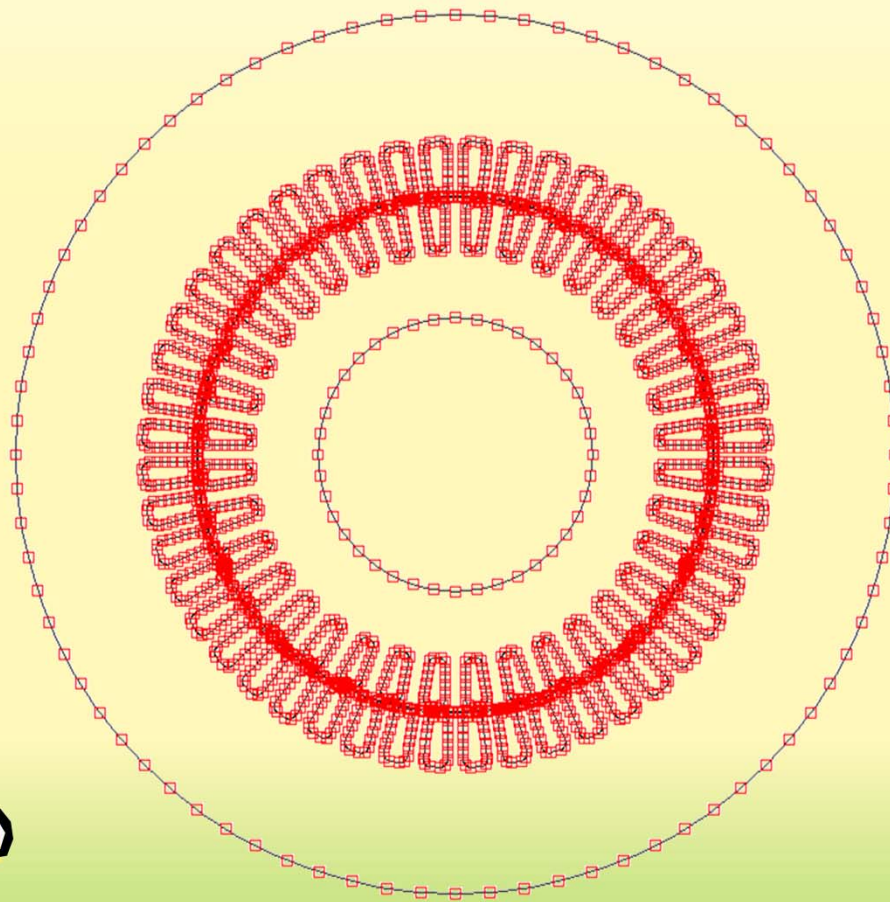
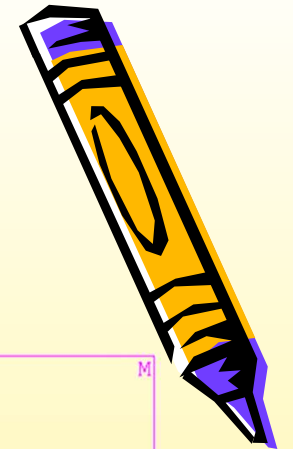
?
OPTIONS
Quit
Zoom
Reset
Move

1 Add
2 Delete
3 Modify
4 See
5 Plot



Realizare structura de discretizare

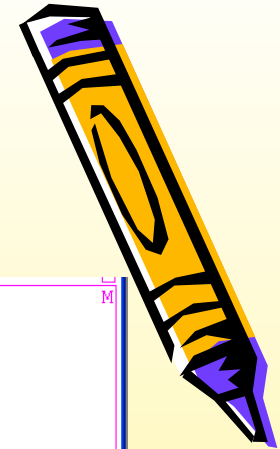
mesh asistat - insertie noduri



```
? M  
OPTIONS  
Quit  
Zoom  
Reset  
Move  
  
1 Initial nodes  
2 Subdivide  
3 Lock line  
4 Unlock line  
5 Mesh  
6 Plot
```



Structura de elemente finite



?
OPTIONS

Zoom
Reset
Move

1 Paint
2 Number
3 Disjoin
4 Display
5 Shell reverse
6 Plot
7 Refuse
8 Accept

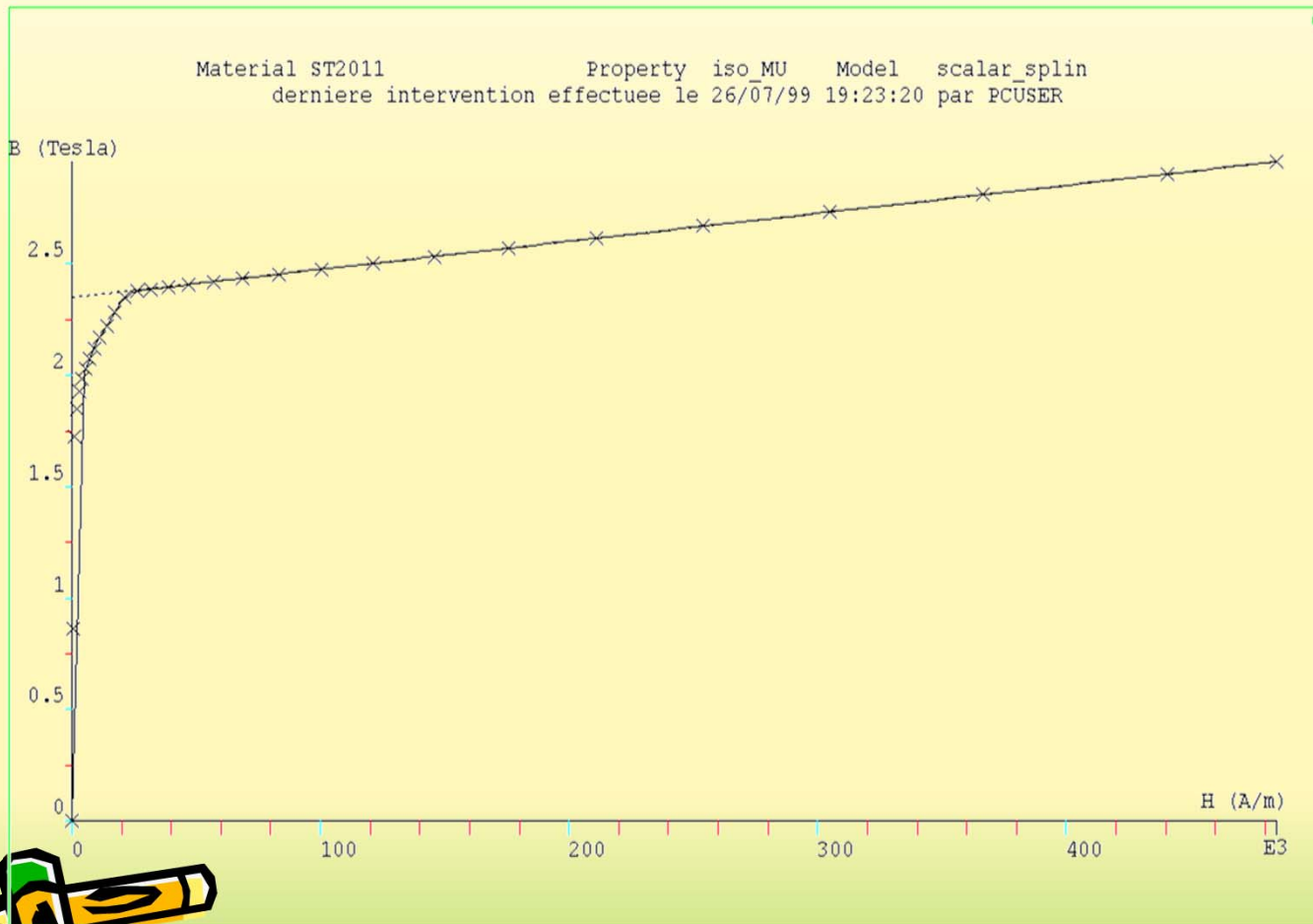
Dialog
10592 surface
Number of nodes : 21265
!!! 73 poor quality elements; they are displayed in green

start ZoneAlarm Security S... MalanducAdina Supervisor FLUX2D 7... preflu EN 11:07



Alocare proprietati de material

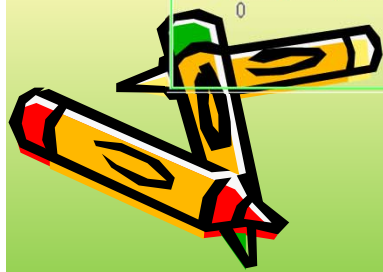
-curba de magnetizate circuit magnetic-



?

Quit

- 1 Pick
- 2 Mod abscissa max
- 3 Modify
- 4 Plot



Conditii de frontiera

-conditii Dirichlet-



The screenshot displays a software window with a central plot area. The plot shows a circular domain with a red dashed outer boundary and a blue solid inner boundary. A menu is open on the right side of the plot area, listing various boundary condition types. Below the plot area, a dialog box is open, prompting the user to select a starting point and a boundary condition type. The Windows taskbar is visible at the bottom of the screen.

Boundary condition type

- ?
0 BREAK
Quit
Zoom
Reset
Move
- 1 Dirichlet
2 Float
3 Cyclic
4 Anticyclic
5 Translation
6 Periodic
8 Cancel
9 List Dirichlet

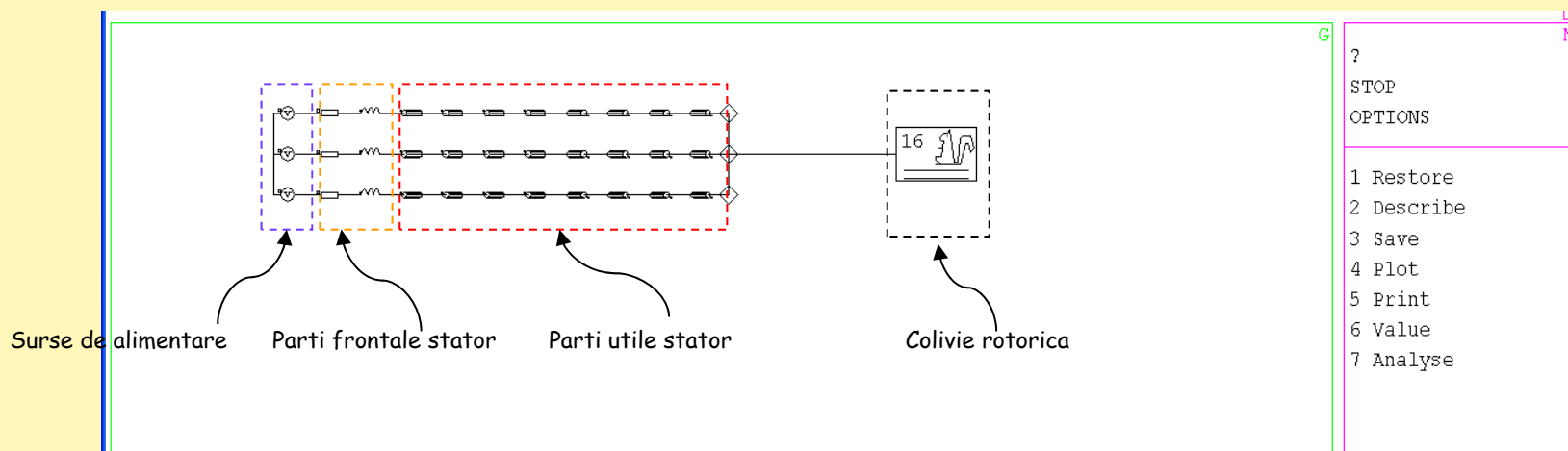
Dialog

0
Please select the starting point
Boundary condition type

start ZoneAlarm Security S... MalenducAdria Supervisor FLUX2D 7... prophy EN 11:17

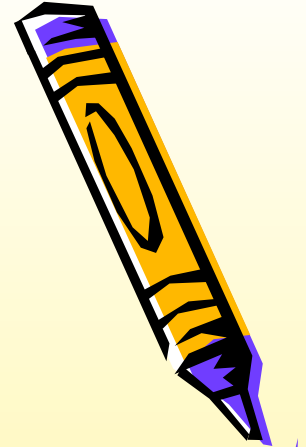


Circuit electric



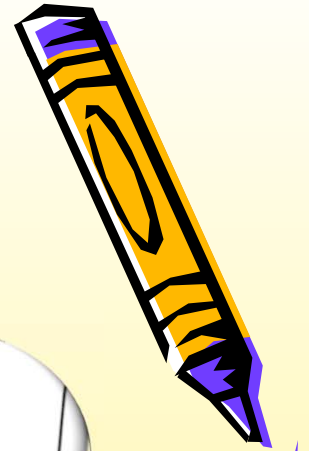
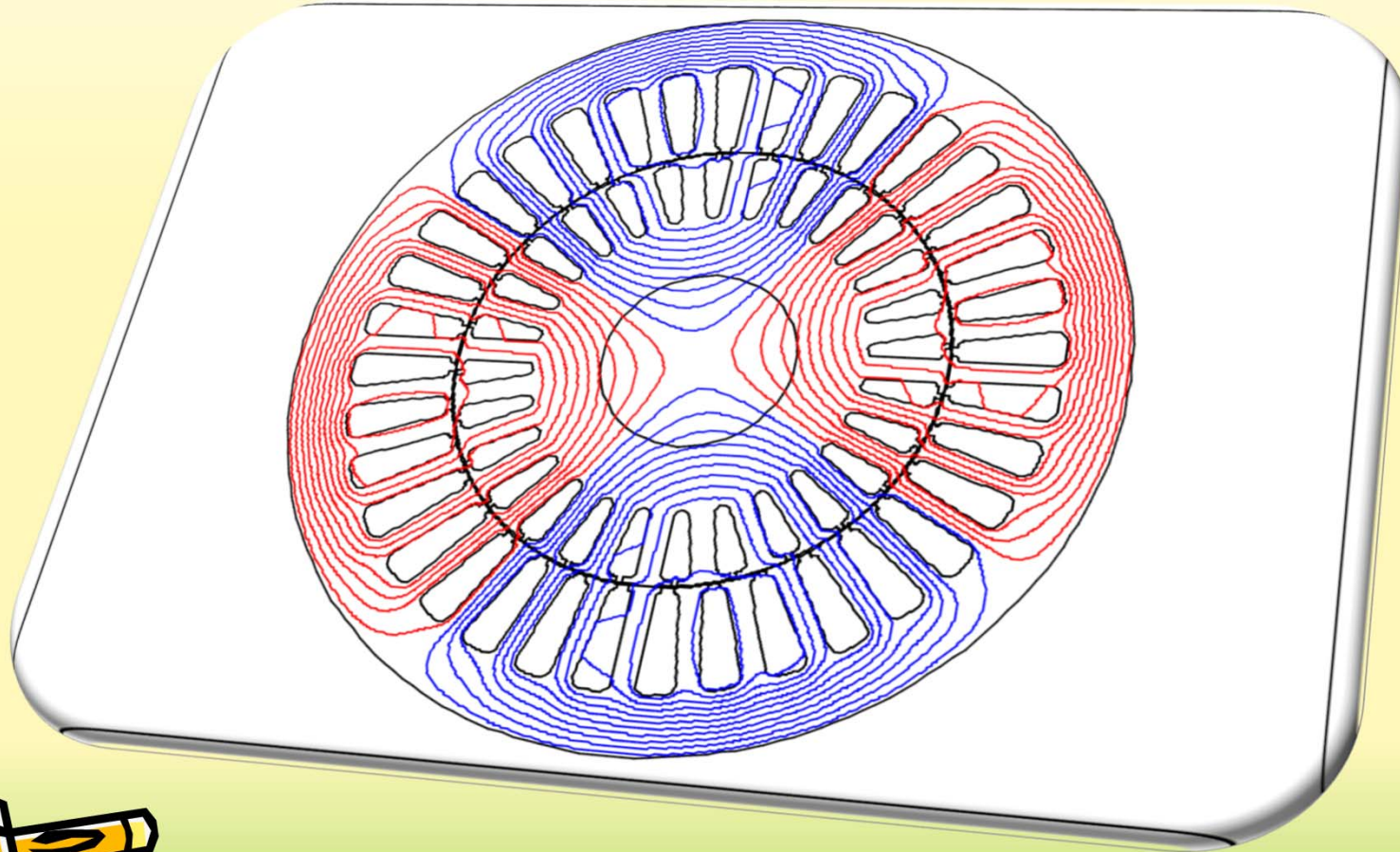
Rezolvare

- Metoda Newton- Raphson
- Metoda algoritmului progresiv se aplica pentru situatiile cu saturatie ridicata



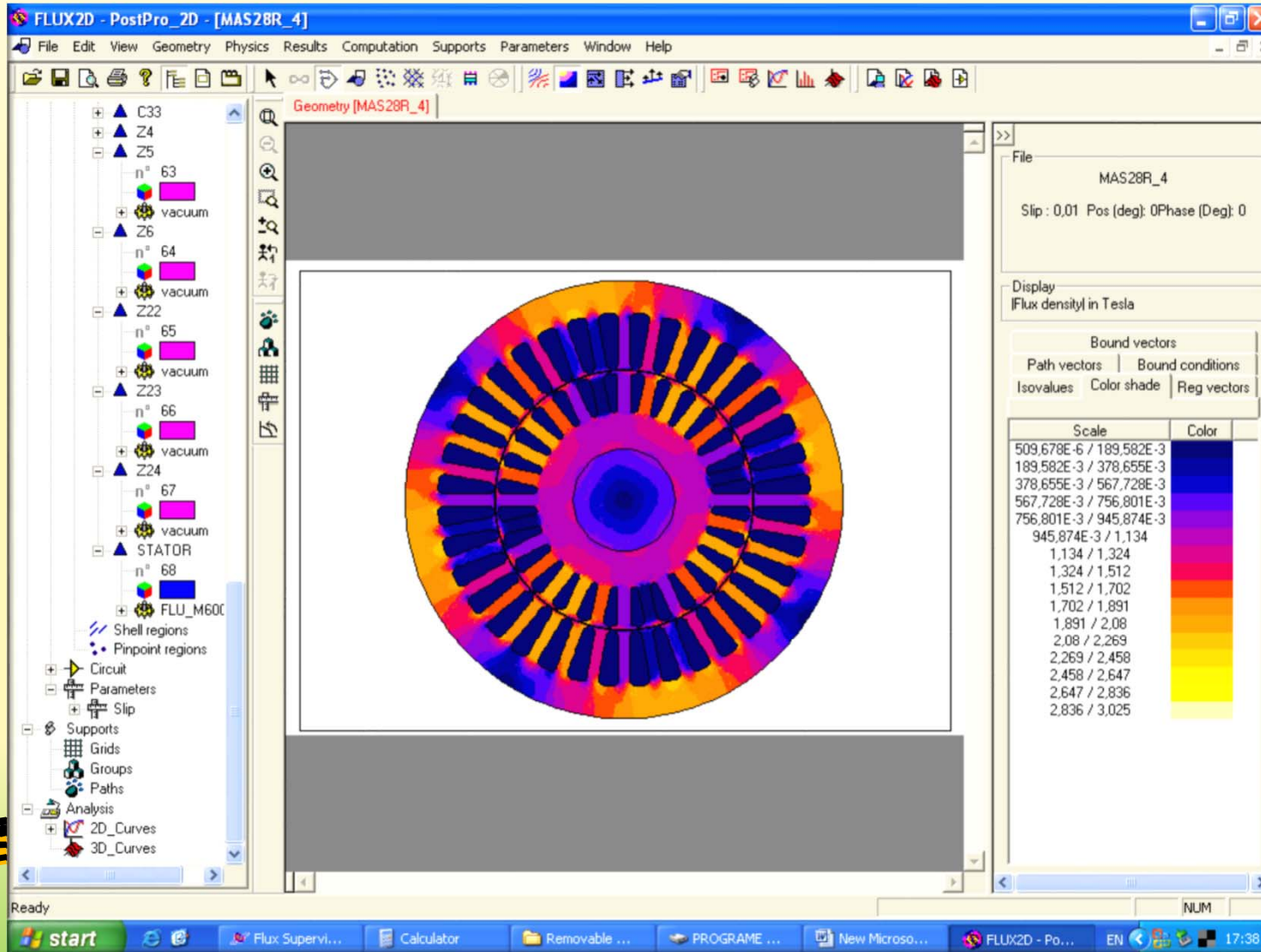
Post-procesare

- distributie linii de camp -



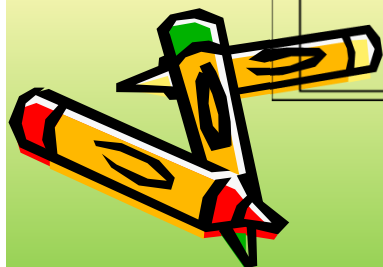
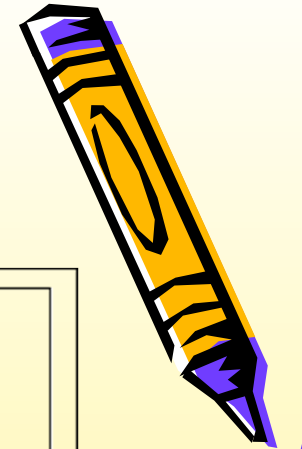
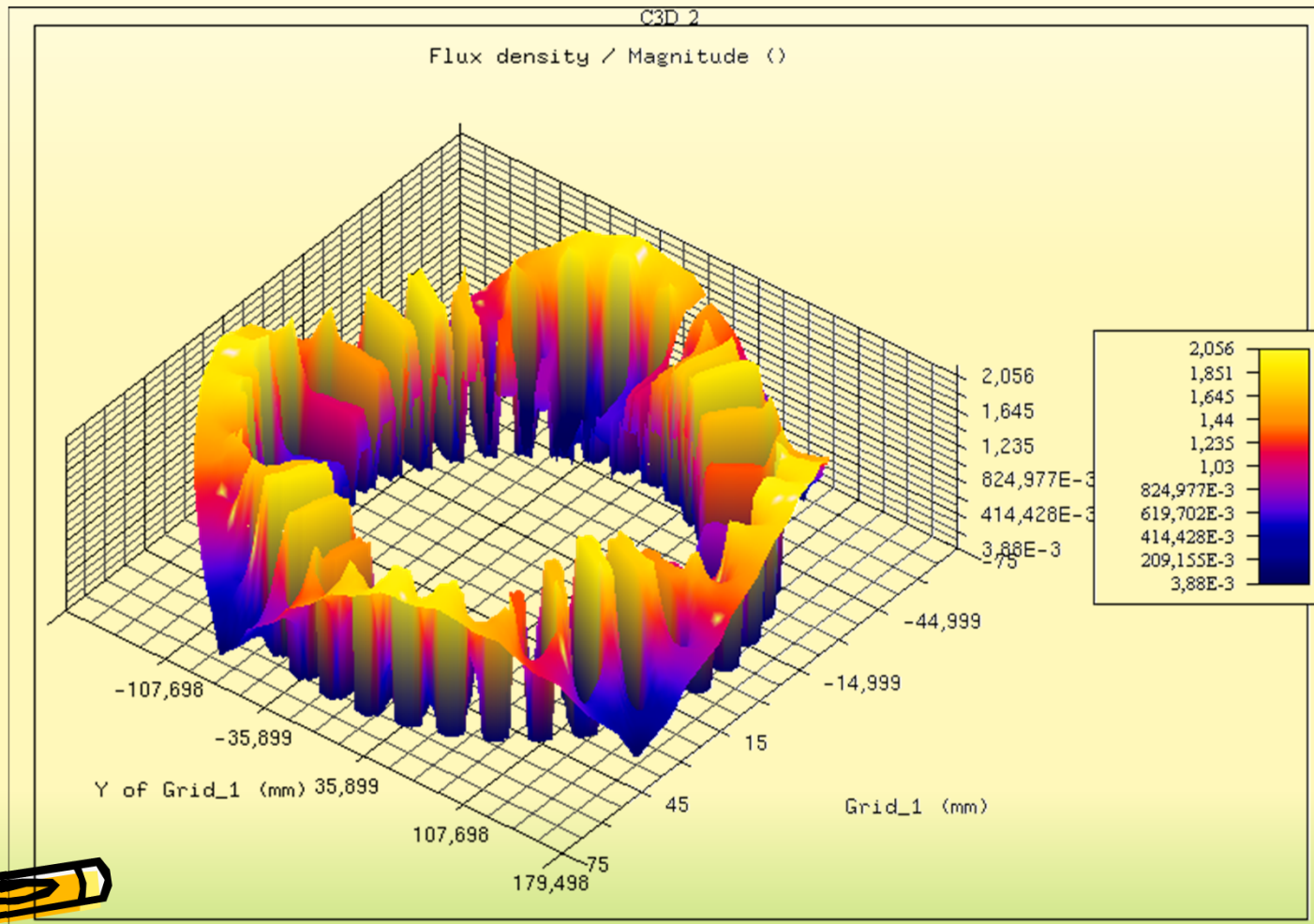
Post-procesare

- harta spectrala a inductiei -



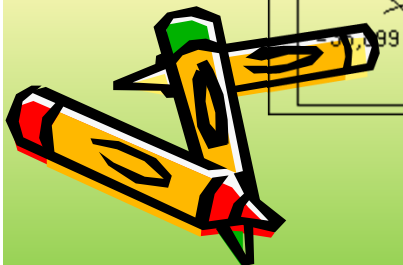
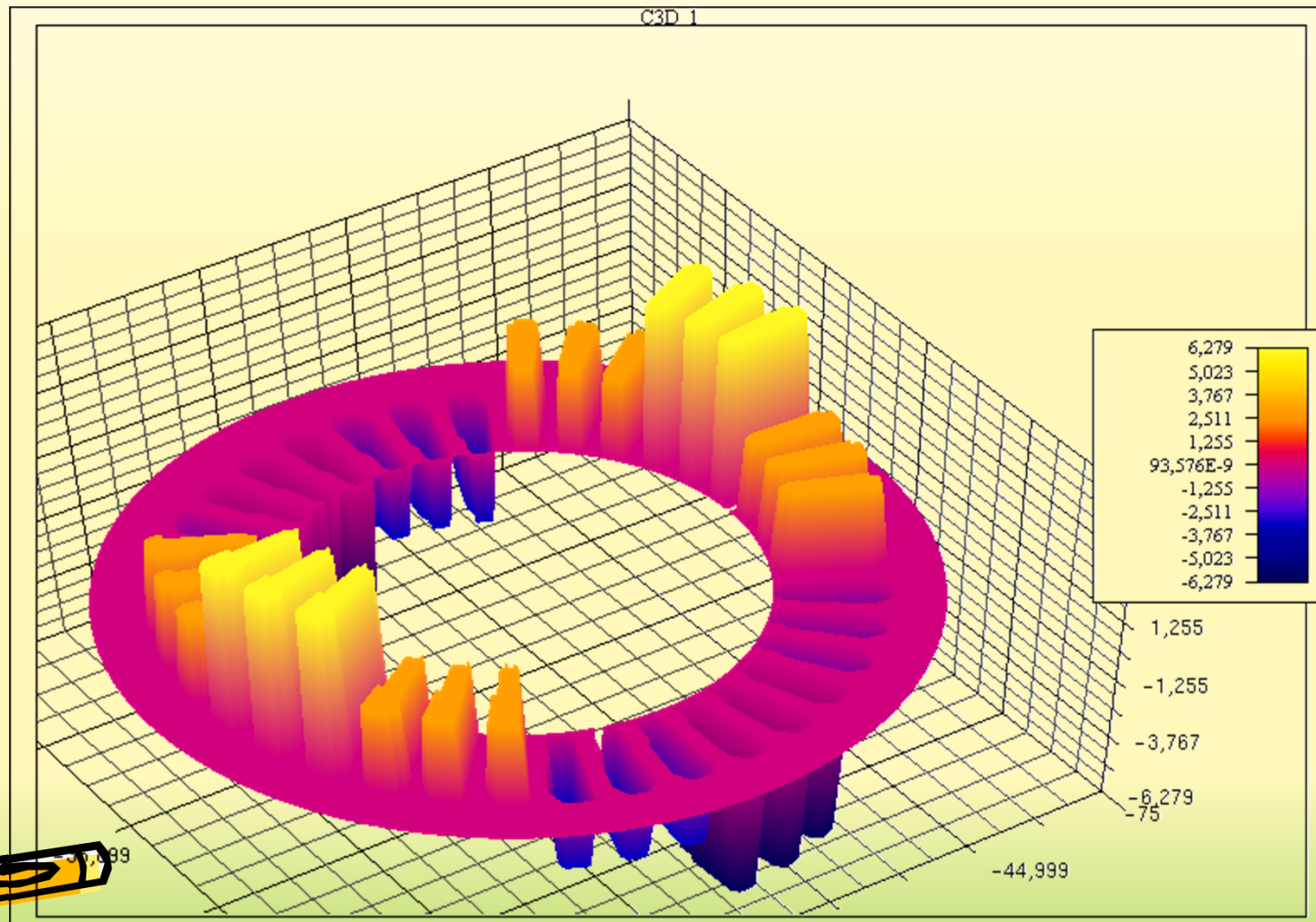
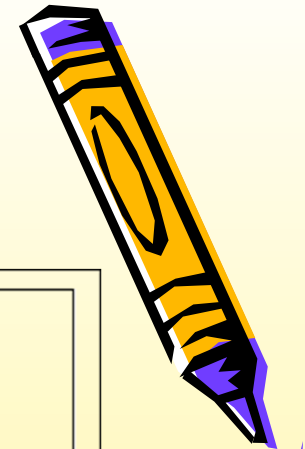
Post-procesare

- harta spectrala a inductiei - distributie 3D



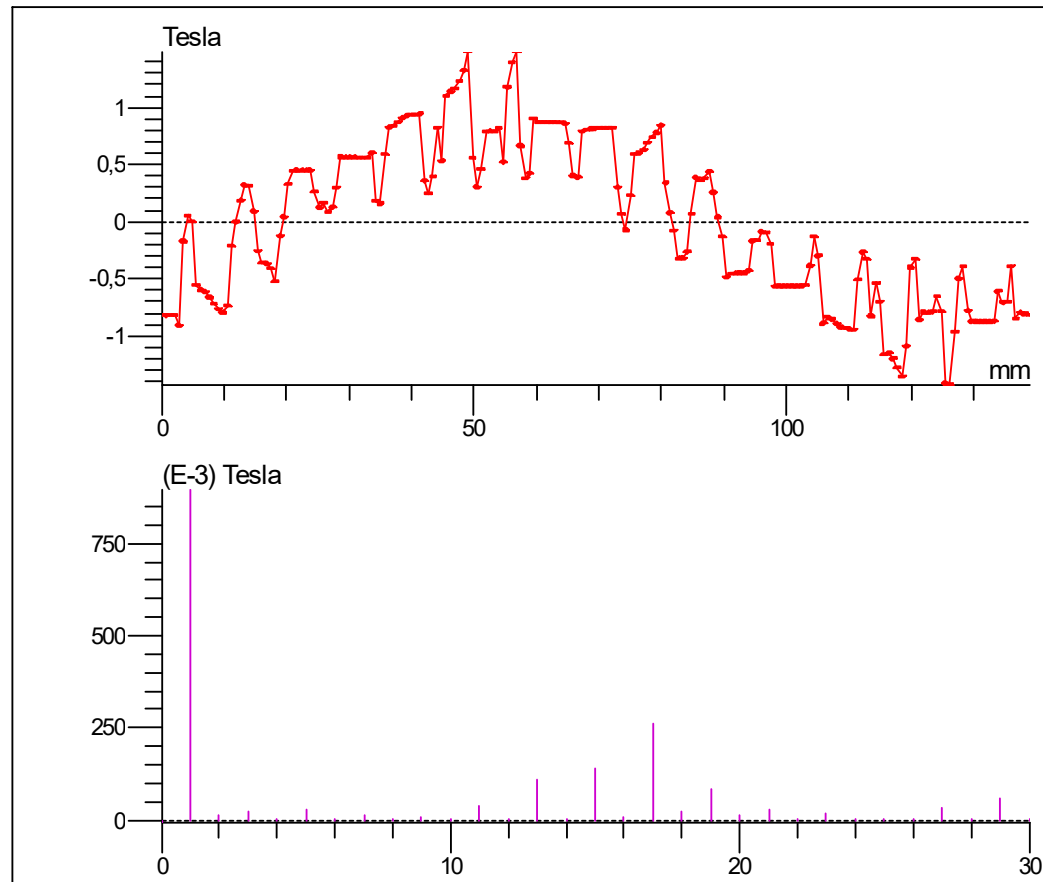
Post-procesare

- distributia densitatii de curent in crestaturi - distributie 3D



Post-procesare

- curba inductiei in intrefier si continutul in armonici -



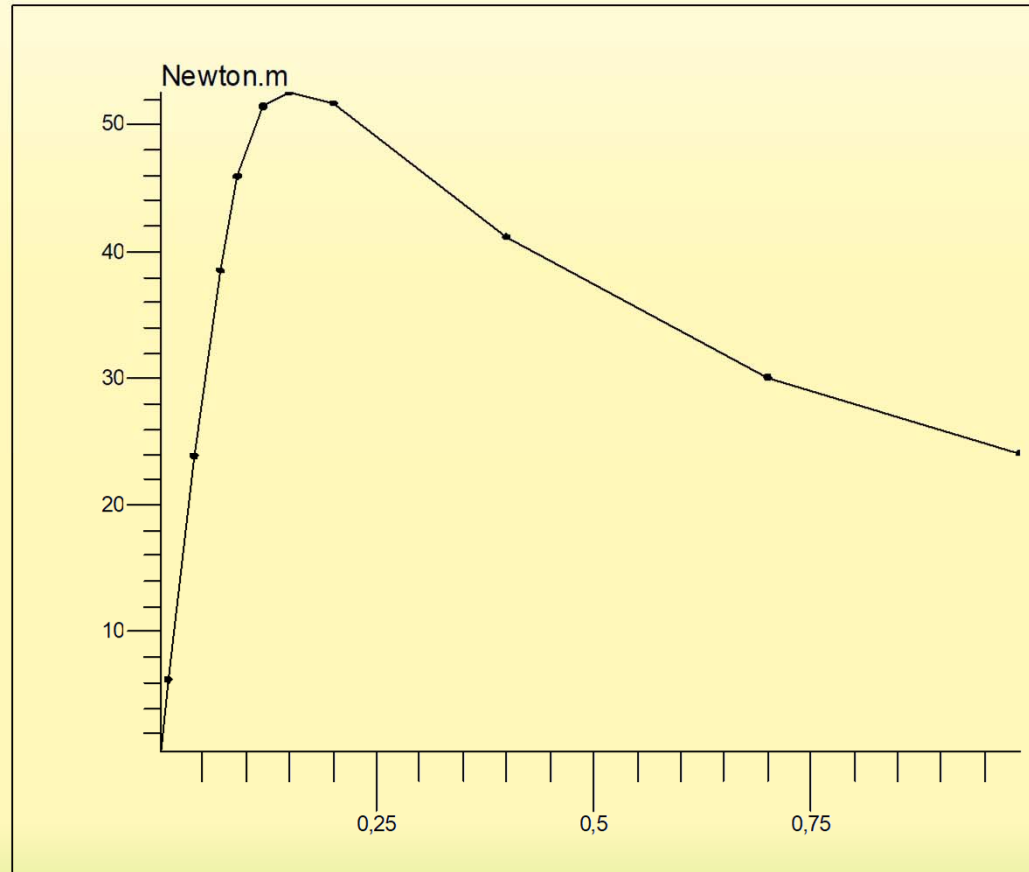
CURVE C2D_2
Flux density / Normal component
Path 1
Slip : 0,04
Phase (Deg): 0
Full cycle / Normal

SPECTRUM Spectr_1
From C2D_2
Fundamental 7,168E-3

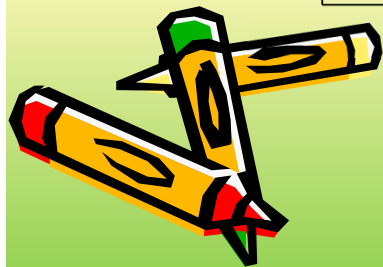


Post-procesare

- curba cuplu-alunecare, $M=f(s)$ -

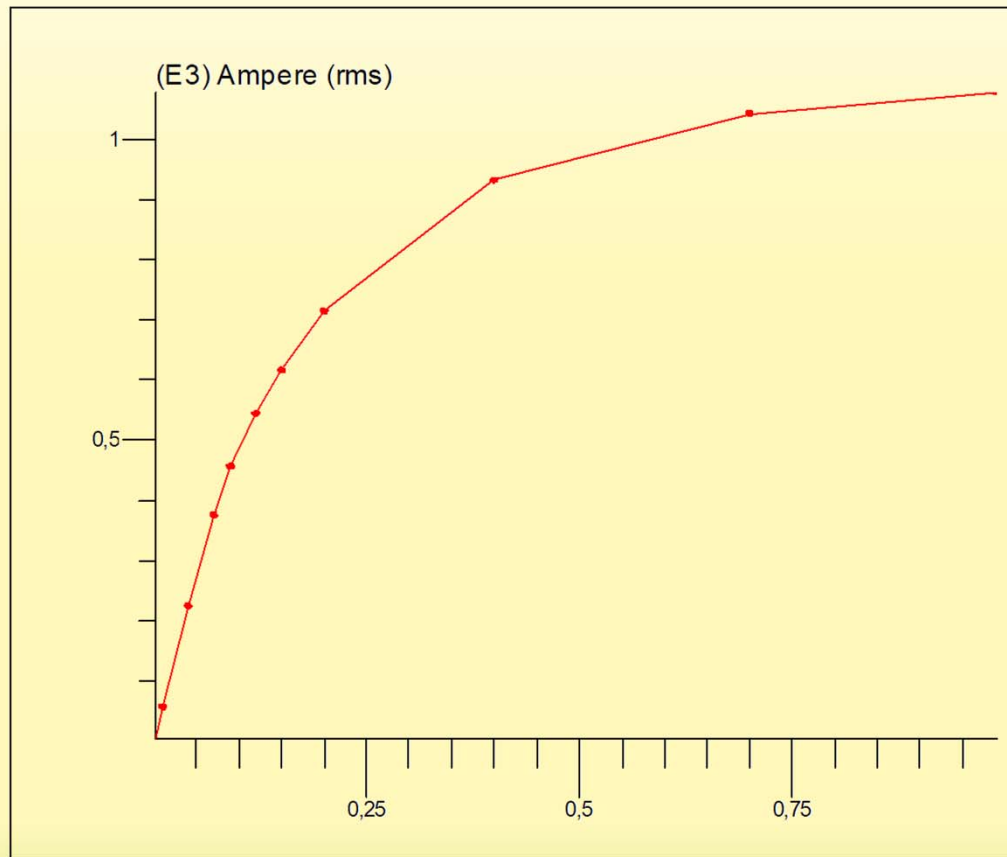


CURVE C2D_1
Torque / Moment
Slip
STATOR ;
Phase (Deg): 0



Post-procesare

- variatia curent-alunecare -



CURVE C2D_3
Current / rms value
Slip
R13 ;
Phase (Deg): 0





G E O M E T R I E

Strategie, mod de abordare





Analiza 2D sau 3D?

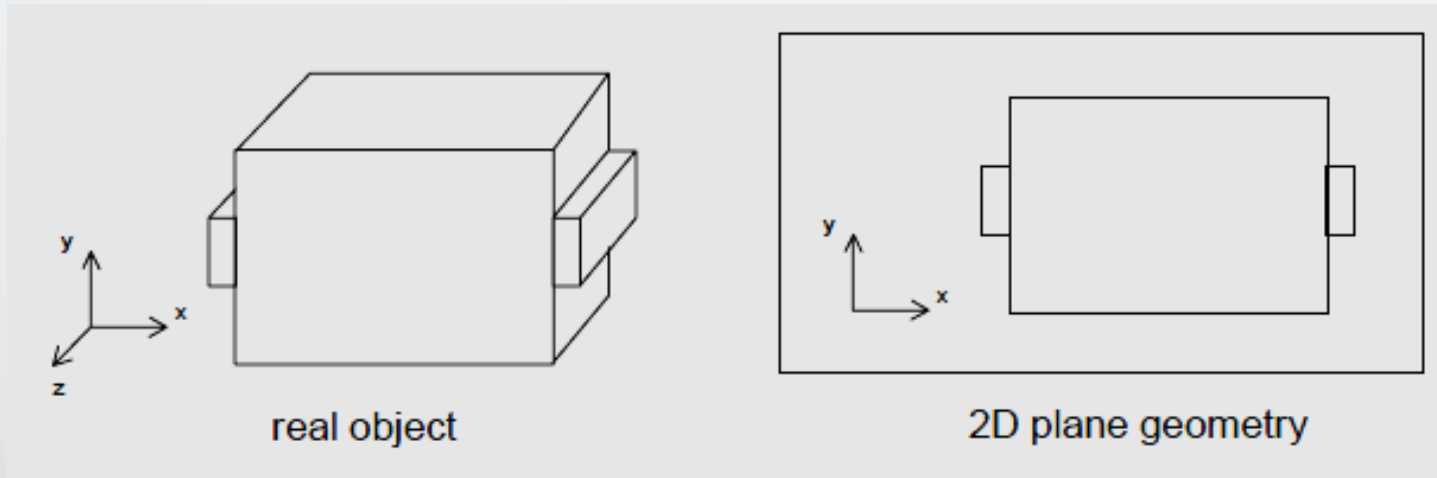
- Daca exista un număr infinit de secțiuni transversale identice de-a lungul unei axe

➡ analiza 2D

- Daca nu exista nici măcar o axa de-a lungul căreia sa existe simetria secțiunilor transversale

➡ analiza 3D

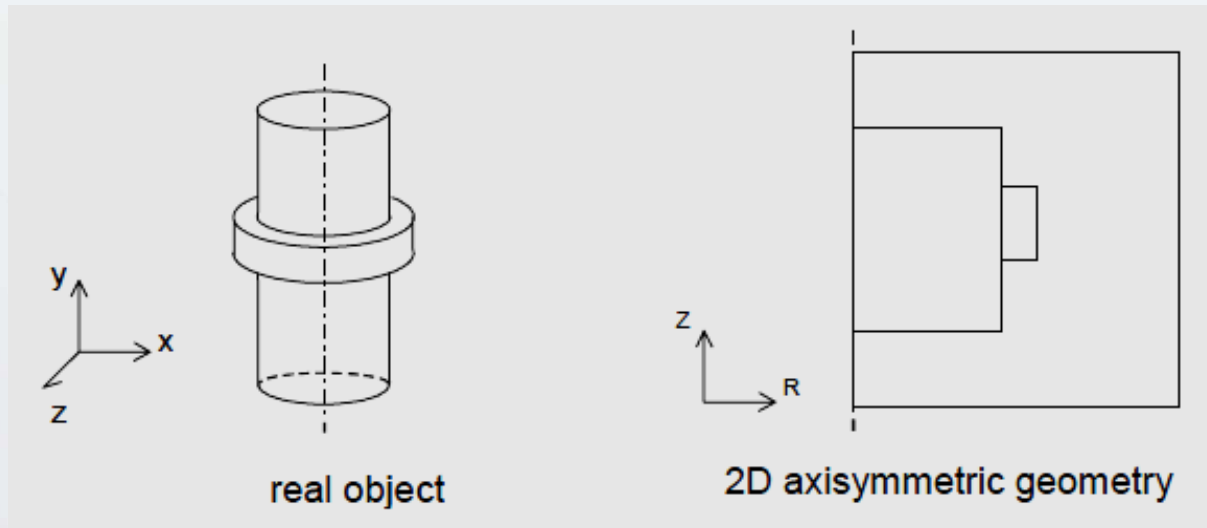
Analiza 2D sau cu simetrie in jurul unei axe (axisymmetric)?



Caracteristici:

- Cel puțin o axa de simetrie
- Reprezentarea geometrica este un plan perpendicular pe direcția axei de simetrie
- Calculul mărimilor globale ia in considerație adâncimea obiectului studiat (dimensiunea după cea de a treia coordonata)

Analiza 2D sau cu simetrie in jurul unei axe (axisymmetric)?



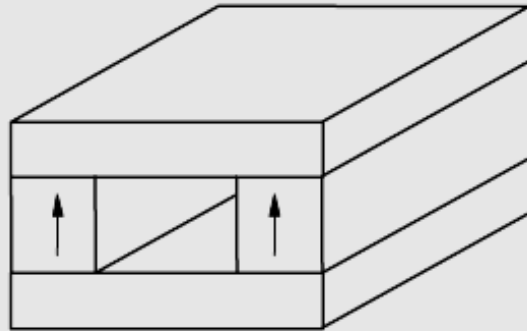
Caracteristici:

- Exista o simetrie de rotație in jurul unei axe
- Axa de revoluție trebuie sa fie obligatoriu verticala si trebuie sa treacă prin originea sistemului de coordonate
- Acest tip de analiza este o abordare 2D ce furnizează însă rezultatele unei evaluări 3D

Analiza 2D sau 3D?

Obiectul de studiu consta in:

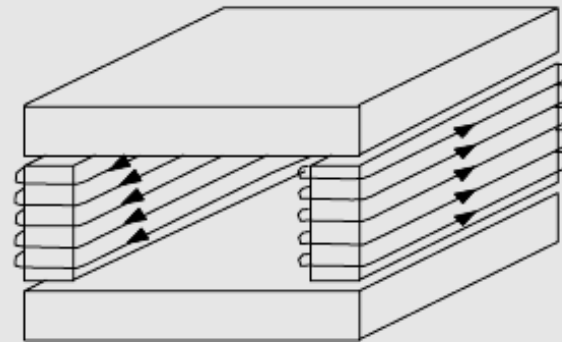
- 2 magneți permanenți in opoziție
- 2 juguri magnetice



Exista un câmp magnetic semnificativ ce iese in afara dispozitivului (flux de dispersie la capete) – analiza 3D

Obiectul de studiu consta in:

- 2 electromagneți
- 2 juguri magnetice



Câmpul magnetic se concentrează in circuitul magnetic – analiza 2D



Definirea limitelor domeniului de studiu

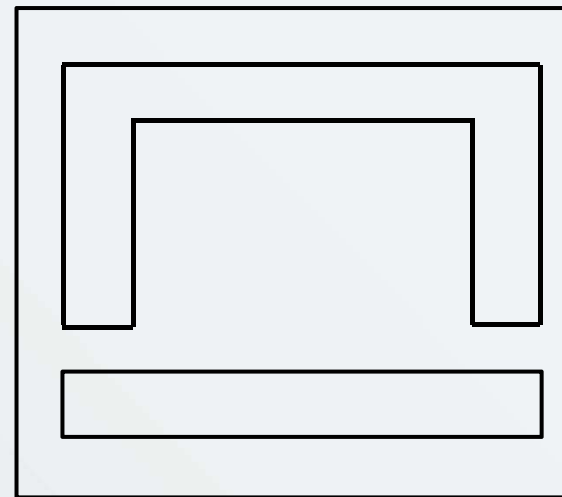
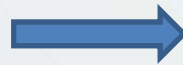
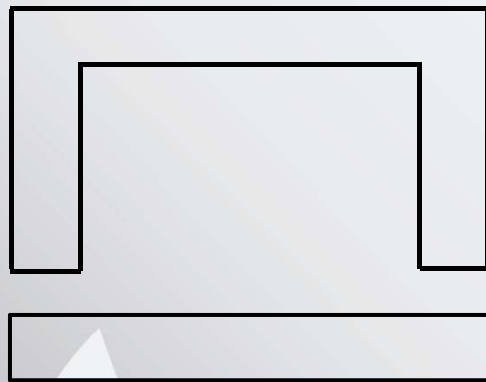
MEF are nevoie (in mod obligatoriu) de precizarea condițiilor de frontiera pe frontierele exterioare (metoda nu poate fi aplicata daca domeniul de studiu este deschis)

Adeseori este necesara determinarea unei soluții a câmpului electromagnetic in afara structurii fizice analizate (in mediul exterior)

Definirea limitelor domeniului de studiu

1. **Metoda trunchierii** – consta in închiderea domeniului de studiu cu o frontiera suficient de îndepărtată de dispozitivul studiat astfel încât sa nu interacționeze cu acesta (cutie umpluta cu aer in care se plasează dispozitivul studiat).

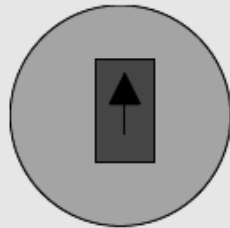
Dezavantaj – creste numărul de elemente si rezulta un timp de calcul mai lung si o putere de calcul mai mare



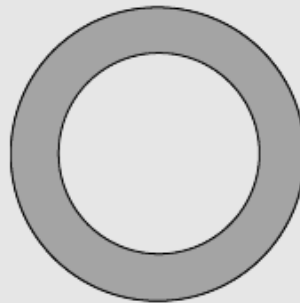
Definirea limitelor domeniului de studiu

2. Metoda „infinite box” – se creează o „cutie” printr-o procedura speciala proprie programului Flux.

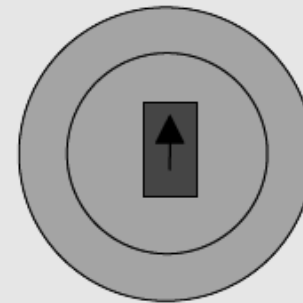
- Pentru analiza 2D acest „infinite box” este format din doua discuri suprapuse ambele având centrul in originea sistemului de coordonate.



Domeniul de studiu



„Infinite box”



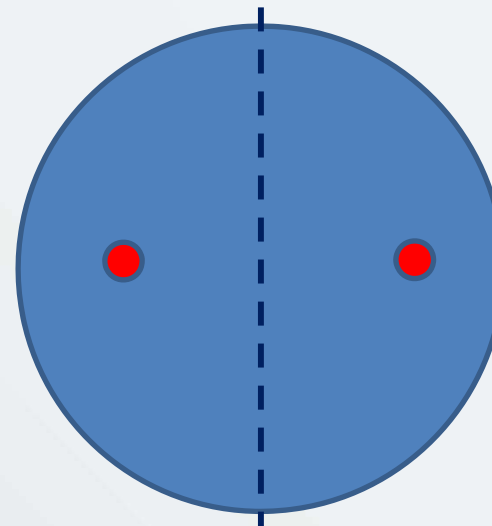
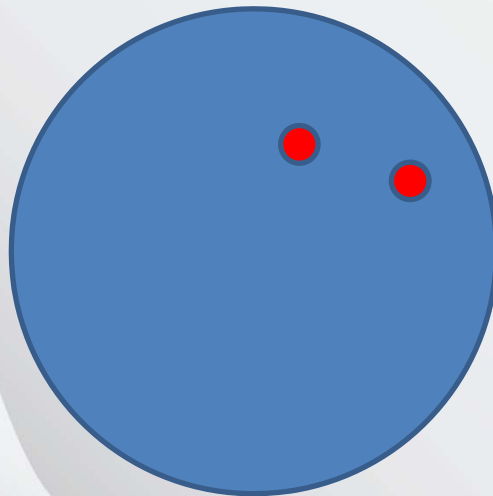
Reprezentare completa

Micșorarea domeniului de studiu

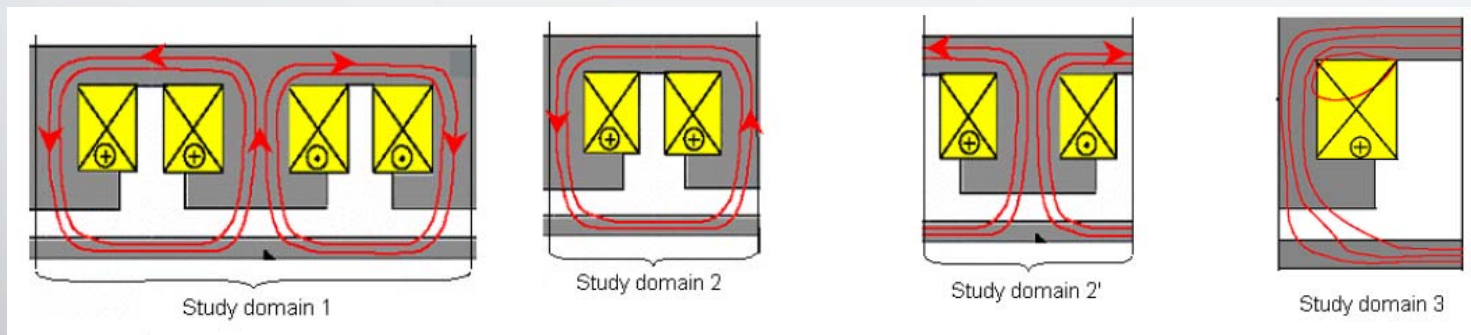
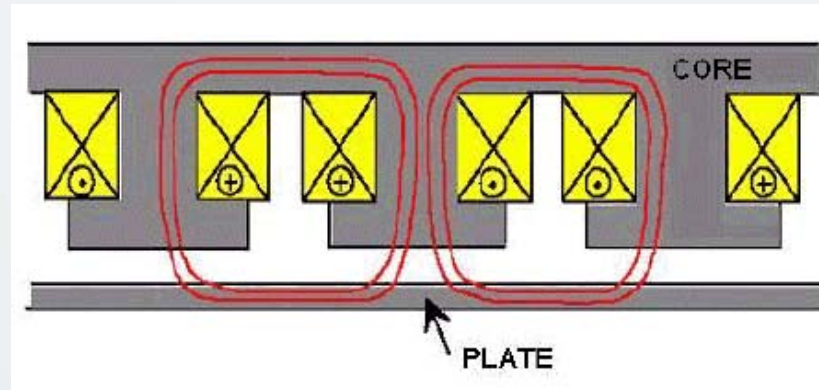
Daca domeniul de studiu poate fi descompus in componente simetrice atunci se poate face o analiza a unui domeniu redus.

Avantaje:

- simplificarea procedurii de realizare a geometriei,
- diminuarea numărului de elemente
- reducerea timpului de calcul
- reducerea mărimii fișierului

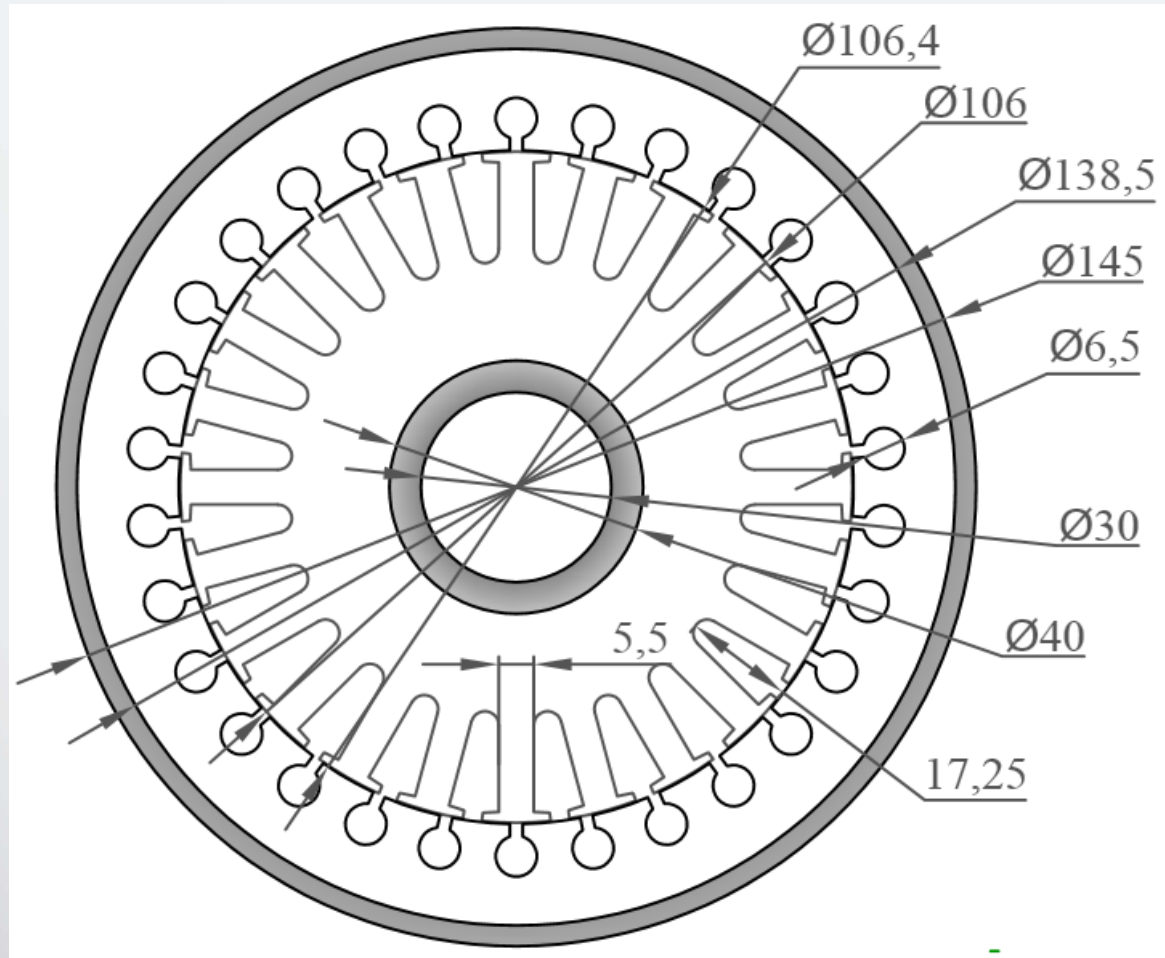


Studiu de caz 1



Domeniul de studiu poate fi redus in subdomenii reprezentative daca exista axe de simetrie.

Studiu de caz 2





Studiu de caz 2

Pentru micșorarea domeniului de studiu este necesara existenta, in planul 2D, a cel puțin unei axe de simetrie

Condiții pentru studiul de caz:

- Numărul de creștături statorice si rotorice sa fie par;
- Structura circuitului magnetic sa fie simetrica după axa de simetrie.

Simetria poate fi identică sau „in oglindă”.

Dacă structura domeniului de studiu o permite, acesta poate fi micșorat la jumătate, o treime, o pătrime, etc.



Studiu de caz 2

Avantaje:

- simplificarea procedurii de realizare a geometriei;
- diminuarea numărului de elemente;
- reducerea timpului de calcul;
- reducerea mărimii fișierului.

Structura de discretizare

Principii



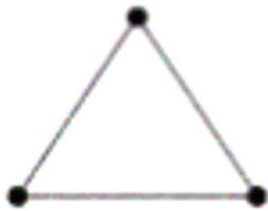
Elemente finite de rețea

Element finit

Funcție de interpolare

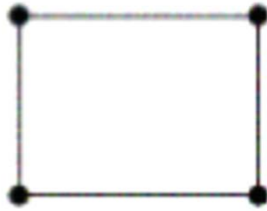
Ordinul I

Triunghi

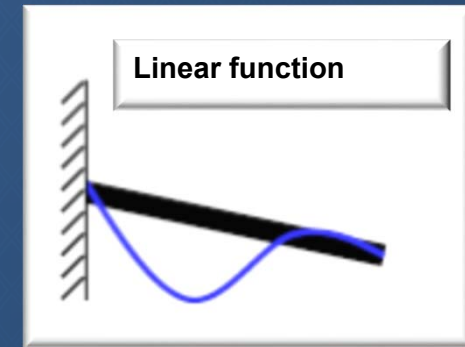


3-noduri

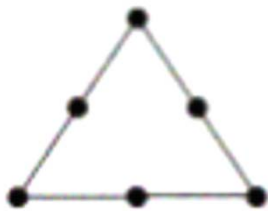
Patrulater



4-noduri



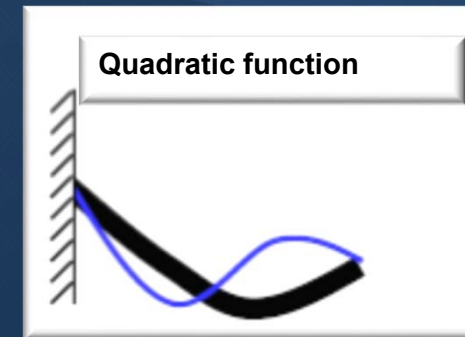
Ordinul II



6-noduri



8-noduri



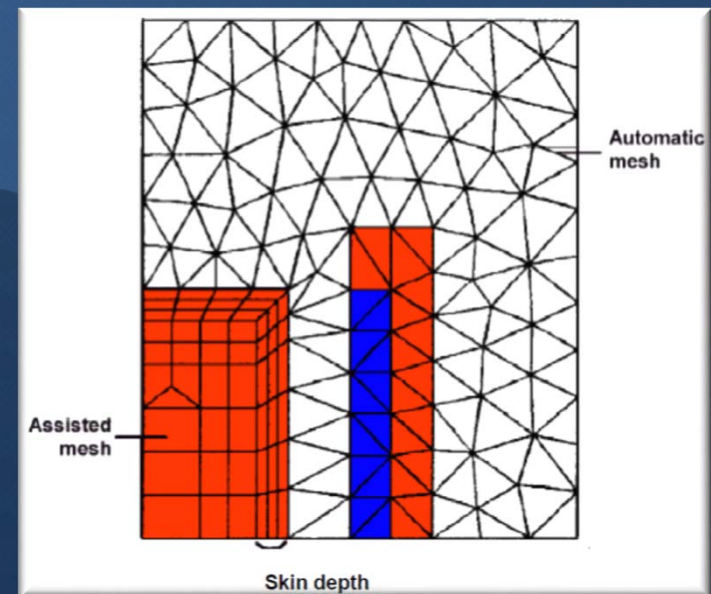
Generarea structurii de discretizare

Generator automat de mesh

- generează NUMAI triunghiuri

Generator asistat de mesh

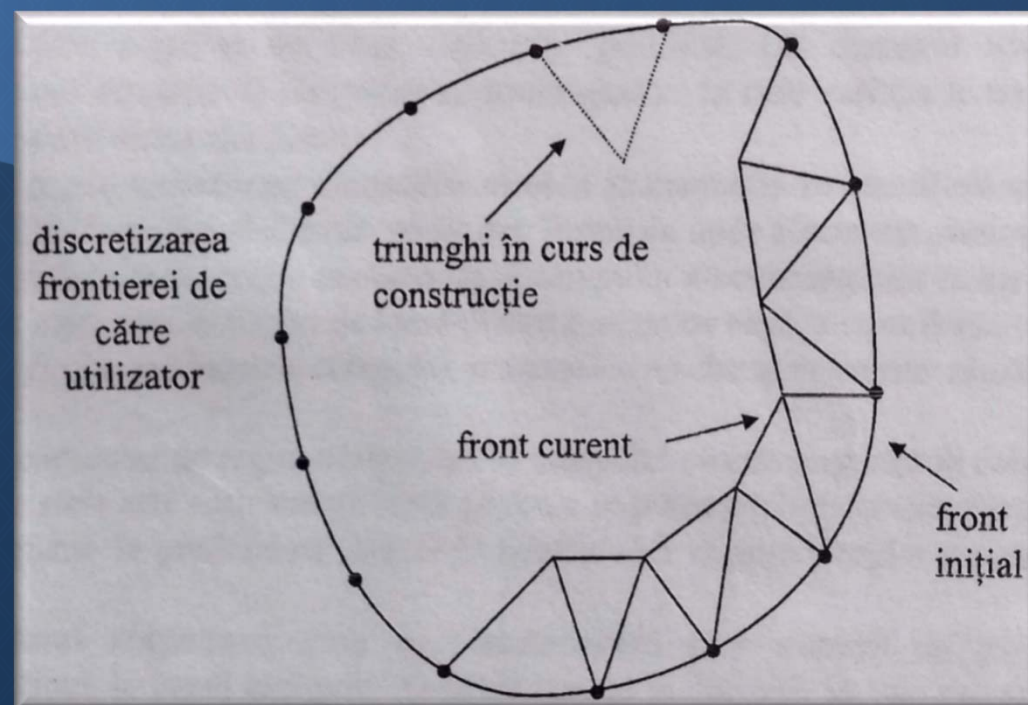
- generează ATÂT triunghiuri CÂT SI patrulatere



Generarea automata a *mesh*-ului

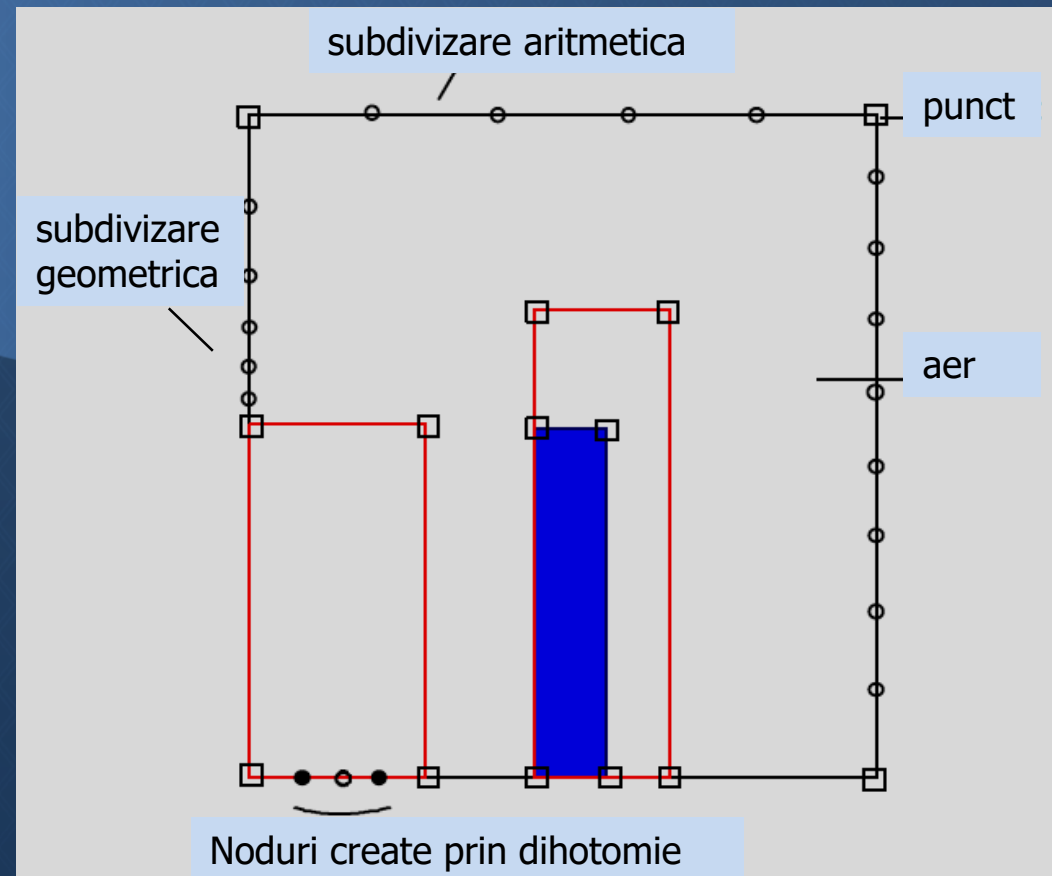
- Folosește nodurile de pe linii
- Pentru generare automata se folosește algoritmul Delaunay

Algoritmul Delaunay creează elemente triunghiulare pornind de la nodurile plasate pe linii și încercând să creeze triunghiuri echilaterale. Întotdeauna se pornește de la frontierele exterioare către interior.



Generarea automata a *mesh*-ului

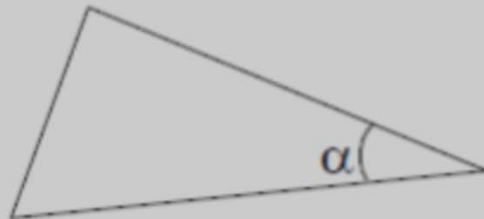
- Subdivizarea aritmetica introduce noduri ce împarte fiecare linie într-un număr de segmente egale (numărul este impus de utilizator)
- Subdivizarea geometrica introduce noduri distanțate inegal; la un capăt al liniei divizate se realizează o densitate mai mare care scade către celălalt capăt al liniei (densitatea este dictată de utilizator prin intermediul unui coeficient).



Verificarea calității elementelor generate

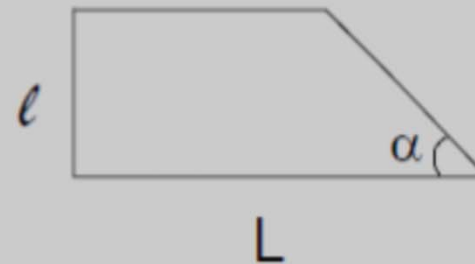
- In cazul triunghiurilor, unghiul cel mai ascuțit trebuie sa fie mai mare de 15°
- In cazul patrulaterelor, unghiul cel mai ascuțit trebuie sa fie mai mare de 20° iar raportul L/l sa fie mai mic decât 5.

triunghiuri



$$\alpha > 15^\circ$$

patrulatere



$$L/l < 5 \quad \alpha > 20^\circ$$

Reguli de urmat pentru un *mesh* valid

1

Elemente finite bine proporționate (ideal: triunghiuri echilaterale și pătrate)

2

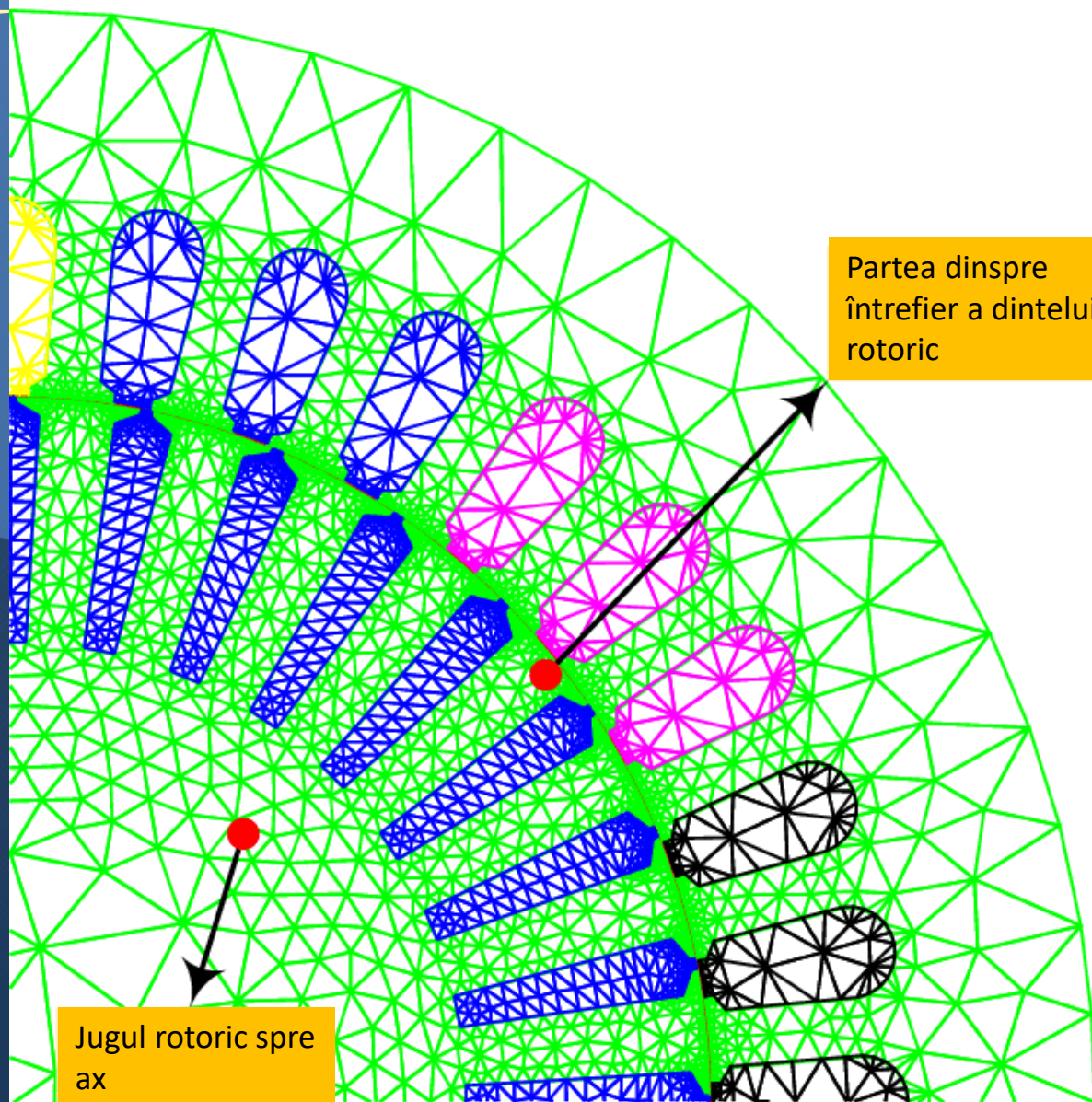
Mesh-ul nu trebuie să fie mai fin decât este necesar

3

Mesh-ul se adaptează la rezultatele ce se doresc a fi obținute

Exemplu

De regula, in zonele de interes se realizează un mesh mai dens, iar in rest mesh-ul poate fi mai rar. In acest fel se limitează numărul global de elemente si noduri.



FEM Pre-processing

Managementul materialelor
- Baza de materiale -



Dep. Elec. Machines

2020-2021

FEM with FLUX

- *Ecuatiile lui Maxwell*

- *Ecuatiile de material*

Material	Ecuatia de material	Caracteristica de material
magnetic	$\vec{B} = \mu \vec{H}$	μ : permeabilitate magnetica [H/m]
dielectric	$\vec{D} = \epsilon \vec{E}$	ϵ : permitivitate electrica [F/m]
conductor	$\vec{J} = \sigma \vec{E}$	σ : conductivitate electrica [$\Omega^{-1}m^{-1}$]



Tipuri de materiale

Proprietăți izotropice ↔ *Proprietăți anizotropice*

Materiale liniare ↔ *Materiale neliniare*

Materiale cu proprietăți de histerezis

*Mărimile ce pot determina modificarea proprietăților
de material: frecvența, temperatura*



Materiale izotrope

- Comportarea materialului, din punct de vedere magnetic, este INDEPENDENTA de direcția de aplicare a câmpului magnetic

(vectorii \vec{B} si \vec{H} sunt întotdeauna coliniari)

$$B = \mu \cdot H$$

$\mu = \text{const.}$ - aproximare liniara

$\mu = \mu(H)$ - aproximare neliniara



Materiale anizotrope

- Comportarea materialului, din punct de vedere magnetic, este DEPENDENTA de direcția de aplicare a câmpului magnetic (ex: magneți permanenți)

(vectorii \vec{B} și \vec{H} nu sunt coliniari)

$$B = [\mu] \cdot H$$

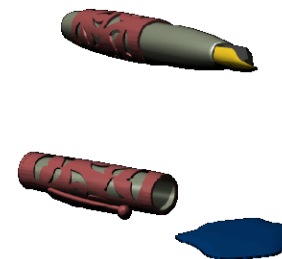
$$[\mu] = \begin{bmatrix} \mu_{xx} & \mu_{xy} & \mu_{xz} \\ \mu_{yx} & \mu_{yy} & \mu_{yz} \\ \mu_{zx} & \mu_{zy} & \mu_{zz} \end{bmatrix}$$

$\mu = \text{const.}$ - *aproximare liniara*

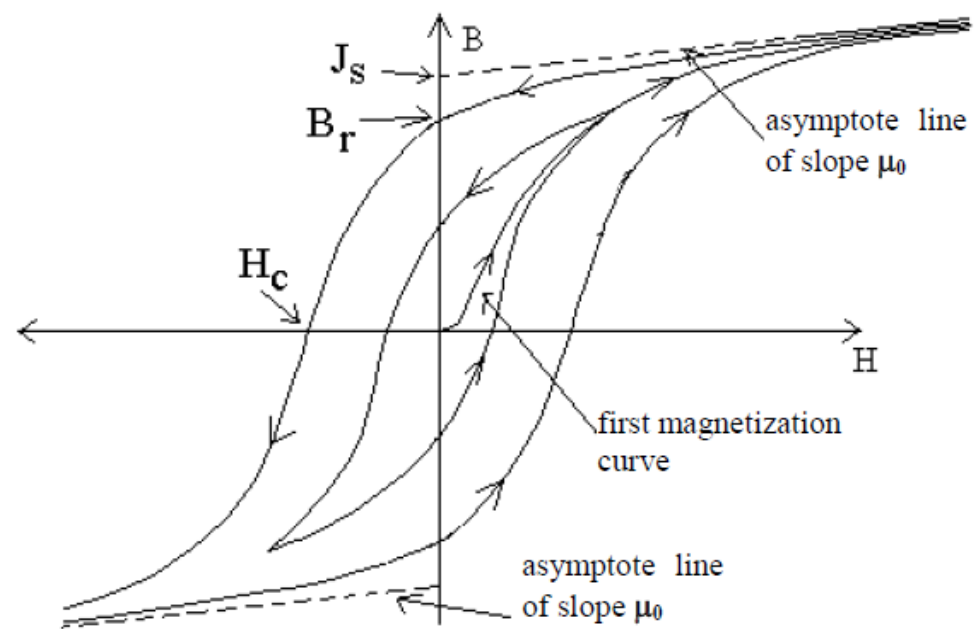
$\mu = \mu(H)$ - *aproximare neliniara*



Medium	Permeability μ [H/m]	Relative permeability μ/μ_0
Metglas	1.26	1000000 ^[7]
Iron (99.95% pure Fe annealed in H)	0.25	200000 ^[8]
Mu-metal	6.3×10^{-2}	50000 ^[11]
Cobalt-Iron (high permeability strip material)	2.3×10^{-2}	18000 ^[12]
Permalloy	1.0×10^{-2}	8000 ^[10]
Iron (99.8% pure)	6.3×10^{-3}	5000 ^[8]
Electrical steel	5.0×10^{-3}	4000 ^[10]
Ferrite (manganese zinc)	$>8.0 \times 10^{-4}$	640 (or more)
Ferrite (nickel zinc)	$2.0 \times 10^{-5} - 8.0 \times 10^{-4}$	16-640
Carbon Steel	1.26×10^{-4}	100 ^[10]
Nickel	$1.26 \times 10^{-4} - 7.54 \times 10^{-4}$	100 ^[10] - 600
Neodymium magnet	1.32×10^{-6}	1.05 ^[15]
Platinum	1.256970×10^{-6}	1.000265
Aluminum	1.256665×10^{-6}	1.000022
Wood	$1.25663760 \times 10^{-6}$	1.0000043 ^[16]
Air	$1.25663753 \times 10^{-6}$	1.0000037 ^[17]
Concrete (dry)		1 ^[18]
Vacuum	$\pi 4 \times 10^{-7} (\mu_0)$	1, exactly ^[19]
Teflon	1.2567×10^{-6} ^[10]	1.0000
Sapphire	1.2566368×10^{-6}	0.99999976
Copper	1.256629×10^{-6}	0.999994
Water	1.256627×10^{-6}	0.999992
Superconductors	0	0



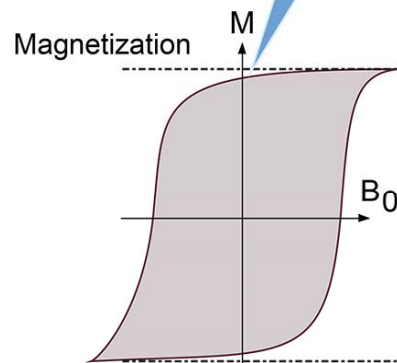
Materiale cu histerezis



Materiale cu histerezis

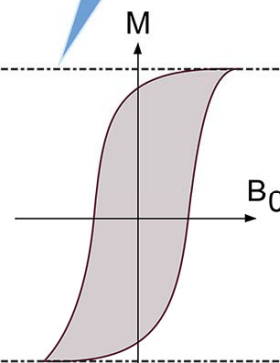
Materiale magnetice dure

Retains a large fraction of the saturation field when driving field removed



Desirable for permanent magnets and magnetic recording and memory devices.

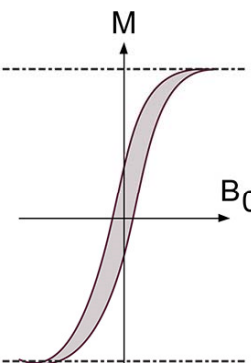
Saturation magnetization



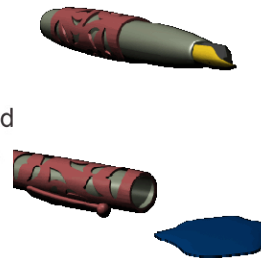
The area of the hysteresis loop is related to the amount of energy dissipation upon reversal of the field.

Materiale magnetice moi

Narrow hysteresis loop implies a small amount of dissipated energy in repeatedly reversing the magnetization



Desirable for transformer and motor cores to minimize the energy dissipation with the alternating fields associated with AC electrical applications.



Aproximare liniara

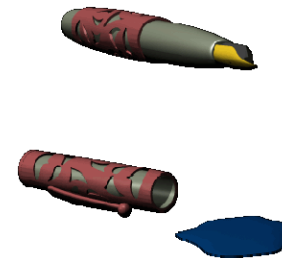
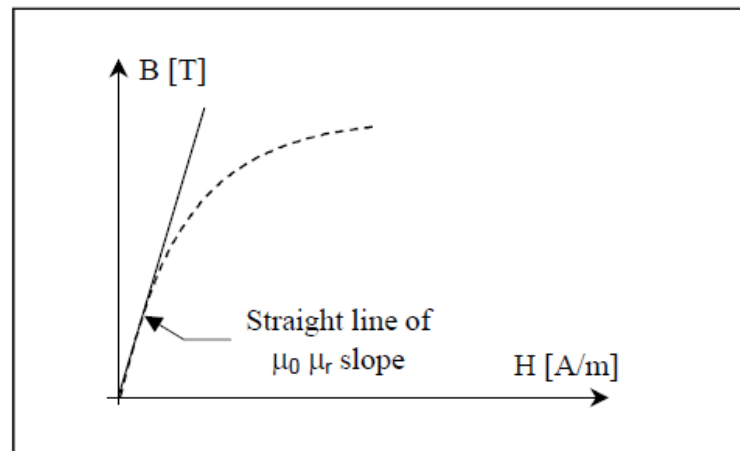
Fenomenul de saturație NU este luat in considerație!

Modelul matematic este reprezentat de o **linie dreapta**.

Relația matematica corespunzătoare este:

$$B(H) = \mu_0 \mu_r H$$

Caracteristica $B=f(H)$ este o dreapta:



Curba de saturație analitică

Fenomenul de saturație este luat în considerație!

Mathematical model

This model is comprised of a **straight line** and an **arc tangent** curve.

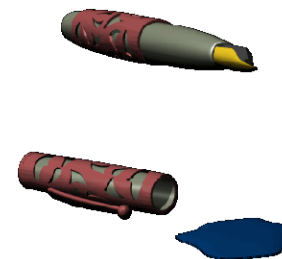
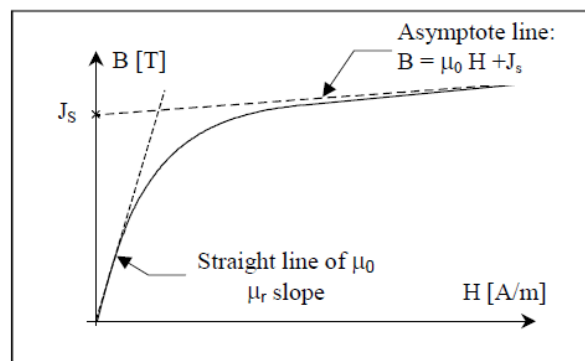
The corresponding mathematical formula is written as:

$$B(H) = \mu_0 H + \frac{2 J_s}{\pi} \operatorname{arctg} \left(\frac{\pi (\mu_r - 1) \mu_0 H}{2 J_s} \right)$$

where:

- μ_0 is the magnetic permeability of vacuum; $\mu_0 = 4 \pi 10^{-7}$ [H/m]
- μ_r is the initial relative magnetic permeability of the material (at the origin)
- J_s is the magnetic polarization at saturation [T]

The shape of this B(H) model is given in the figure below.



Curba analitica+ ajustarea arcului de saturație

Fenomenul de saturație este luat in considerație!

Mathematical model

This model consists, like the previous one, of a combination of a straight line and a curve. A coefficient allows for the adjustment of the knee shape in order to better approximate the experimental curve.

The corresponding mathematical formula is written as follows:

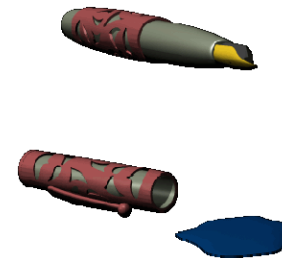
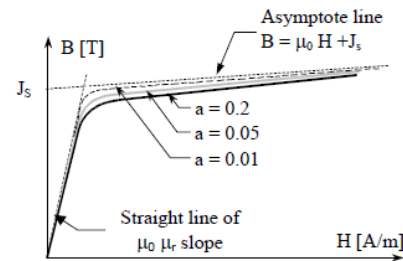
$$B(H) = \mu_0 H + J_s \frac{H_a + 1 - \sqrt{(H_a + 1)^2 - 4 H_a (1 - a)}}{2(1 - a)}$$

$$\text{with } H_a = \mu_0 H \frac{\mu_r - 1}{J_s}$$

where:

- μ_0 is the magnetic permeability of vacuum ; $\mu_0 = 4 \pi 10^{-7}$ [H/m]
- μ_r is the initial relative magnetic permeability of the material (at the origin)
- J_s is the magnetic polarization at saturation [T]
- a is the adjustment coefficient of the B(H) curve knee ($0 < a < 0.5$)
The smaller the coefficient, the sharper the knee is.

The shape of this B(H) model is given in the figure below.



Curba de saturație tip „spline”

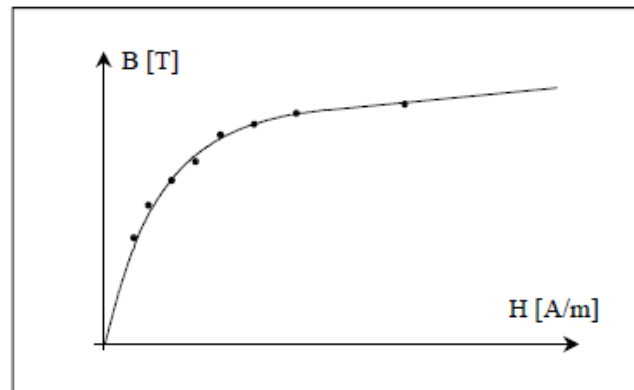
Fenomenul de saturație este luat in considerație!

Mathematical model

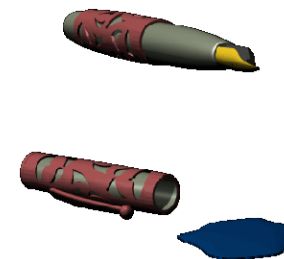
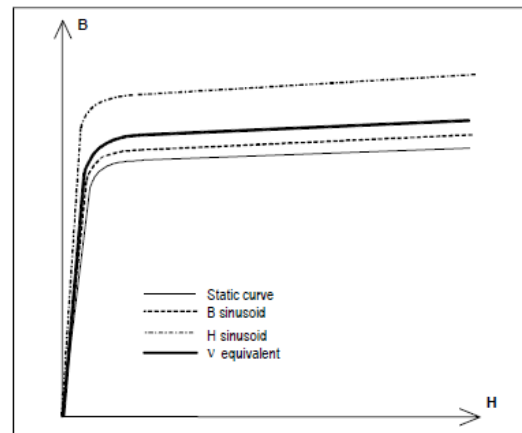
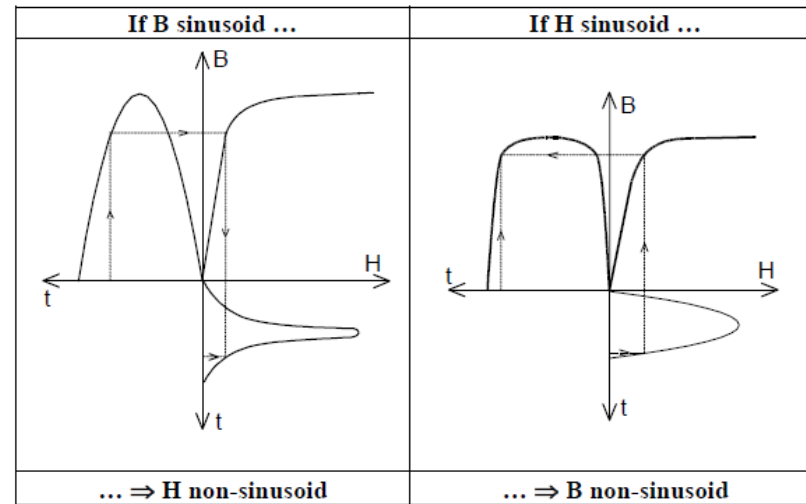
The model is constructed in the following manner:

- entry of **experimental B, H** values
- interpolation by a spline function

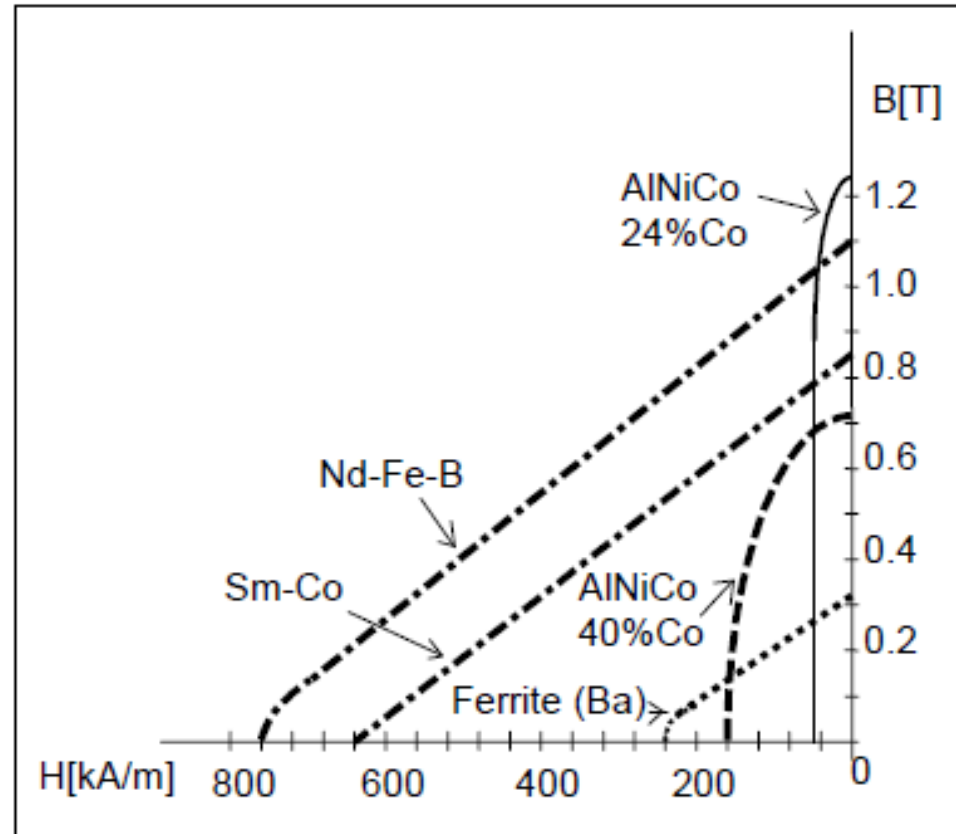
The shape of the B(H) curve is given in the figure below.



Steady state AC magnetic applications



Magneți permanenți



Aproximare liniara

Mathematical model

In the direction of magnetization the model is a **straight line**.

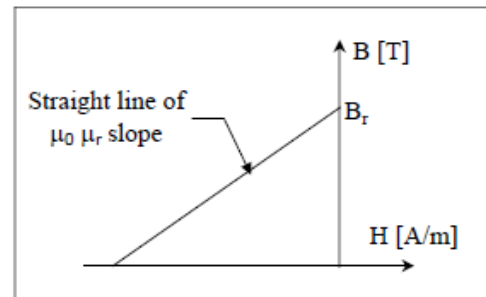
The corresponding mathematical formula is written as follows:

$$B(H) = \mu_0 \mu_r H + B_r$$

where:

- μ_0 is the magnetic permeability of vacuum, $\mu_0 = 4 \pi 10^{-7}$ [H/m]
- μ_r is the relative magnetic permeability (recoil line slope)
- B_r is the remanent flux density [T]

The shape of the B(H) dependence is given in the figure below.



Curba de demagnetizare (B_r si H_c)

Mathematical model

In the direction of magnetization the model is a combination of a **straight line** and an **arc tangent curve**.

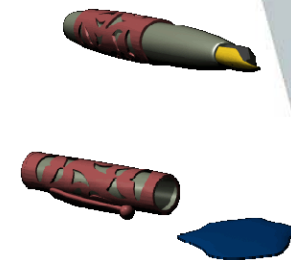
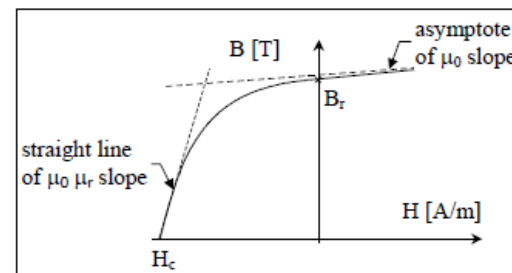
The corresponding mathematical formula is written:

$$B(H) = \mu_0(H + H_c) + (B_r - \mu_0 H_c) \left[\operatorname{arctg} \left(\frac{\pi(\mu_r - 1)\mu_0(H + H_c)}{2B_r} \right) / \operatorname{arctg} \left(\frac{\pi(\mu_r - 1)\mu_0 H_c}{2B_r} \right) \right]$$

where:

- μ_0 is the magnetic permeability of vacuum; $\mu_0 = 4 \pi 10^{-7}$ [H/m]
- μ_r is the relative magnetic permeability of material (for $H = H_c$)
- B_r is the remanent flux density [T]
- H_c is the coercive field strength [A/m]

The shape of the $B(H)$ dependence in the direction of magnetization is given in the opposite figure.



Curba de demagnetizare+arc ajustabil

Mathematical model

In the **direction of magnetization** the model is a combination of a **straight line** and an **arc tangent curve**. A coefficient adjusts the shape of the curve knee for a better approximation of the experimental curve

The corresponding mathematical formula is written:

$$B(H) = \mu_0 (H + H_c) + (B_r - \mu_0 H_c) \text{Coef}B_r / \text{Coef}B_{r0} \quad (\text{for } H + H_c > 0)$$

with $\text{Coef}B_r = \left(Ha + 1 - \sqrt{(Ha + 1)^2 - 4Ha(1 - a)} \right)$ and $Ha = \mu_0 (H + H_c) \frac{\mu_r - 1}{B_r}$

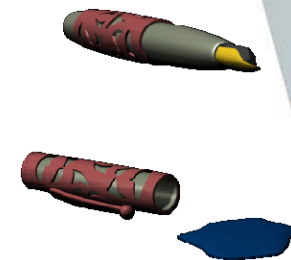
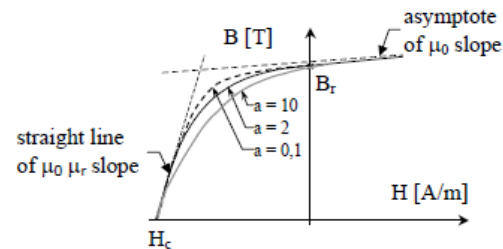
$\text{Coef}B_{r0} = \left(Ha_0 + 1 - \sqrt{(Ha_0 + 1)^2 - 4Ha_0(1 - a)} \right)$ and $Ha_0 = \mu_0 H_c \frac{\mu_r - 1}{B_r}$

where:

- μ_0 is the magnetic permeability of vacuum; $\mu_0 = 4 \pi 10^{-7}$ [H/m]
- μ_r is the relative magnetic permeability of material (for $H = H_c$)
- B_r is the remanent flux density [T]
- H_c is the coercive field strength [A/m]
- a is the knee adjustment coefficient ($a > 0$; $a \neq 1$)

The smaller the coefficient, the sharper the knee is.

The shape of the $B(H)$ dependence in the direction of magnetization is given in the opposite figure.



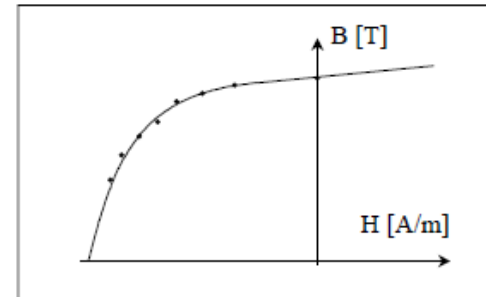
Curba de demagnetizare tip „spline”

Mathematical model

In the direction of magnetization the model is constructed in the following manner:

- entry of **experimental B, H** values
- interpolation by a spline function

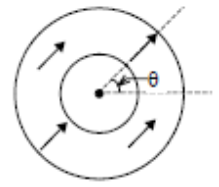
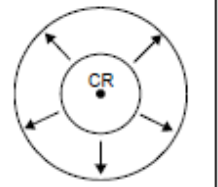
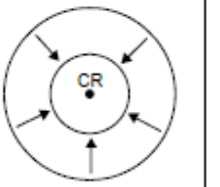
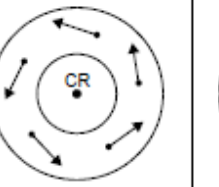
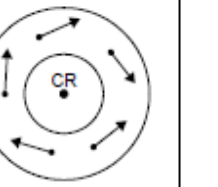
The shape of the $B(H)$ dependence in the direction of magnetization is given in the opposite figure.



Directii de magnetizare

Directia de magnetizare a magnetului permanent este definită in mod separat in program (etapa de alocare a proprietăților de material).

In planul XOY, exista următoarele posibilități de alocare a direcțiilor de magnetizare.

				
Unidirectional	Radial positive	Radial negative	Orthoradial positive	Orthoradial negative



Tipuri de aplicații

Application	Magnetic properties		Electric and dielectric properties				Thermal properties			
	Rel. perm.	Rem. magn.	Rel. peritvity	Angle of diel. loss	Resistivity normal source	Resistivity tang. source	Thermal conductivity	Specific heat	Coef. of convection	Emissivity
Magnetostatics	x	x								
Transient magnetics	x	x			x					
Magnetodynamics	x				x					
Electrostatics			x	x						
Dielectrics			x	x		x				
Electrokinetics						x				
Electrodynamics	x					x				
Steady state thermal							x		x	x
Transient thermal							x	x	x	x
Magneto-thermal coupling	x				x		x	x	x	x
Electro-thermal coupling						x	x	x	x	x
Dielectro-thermal coupling			x	x		x	x	x	x	x



Lista proprietăților fizice

Physical property	isotropic	anisotropic
Real relative permeability: μ_r	[1_iso_MU]	[2_ani_MU]
Complex relative permeability: μ_r	[F_Cmplx_MU]	
Relative permeability depending on T: μ_r	[E_MU(T)]	
Remanent flux density : B_r	[5_Magnet]*	
Electric resistivity: ρ	[3_iso_RHO]	[4_ani_RHO]
Real relative permittivity: ϵ_r	[6_iso_EPS]	[7_ani_EPS]
Dielectric loss angle: $\tan \delta$	[8_Tg_delta]	
Thermal conductivity: k	[9_iso_K]	[A_ani_K]
Specific heat: ρC_p	[B_ROcp]	

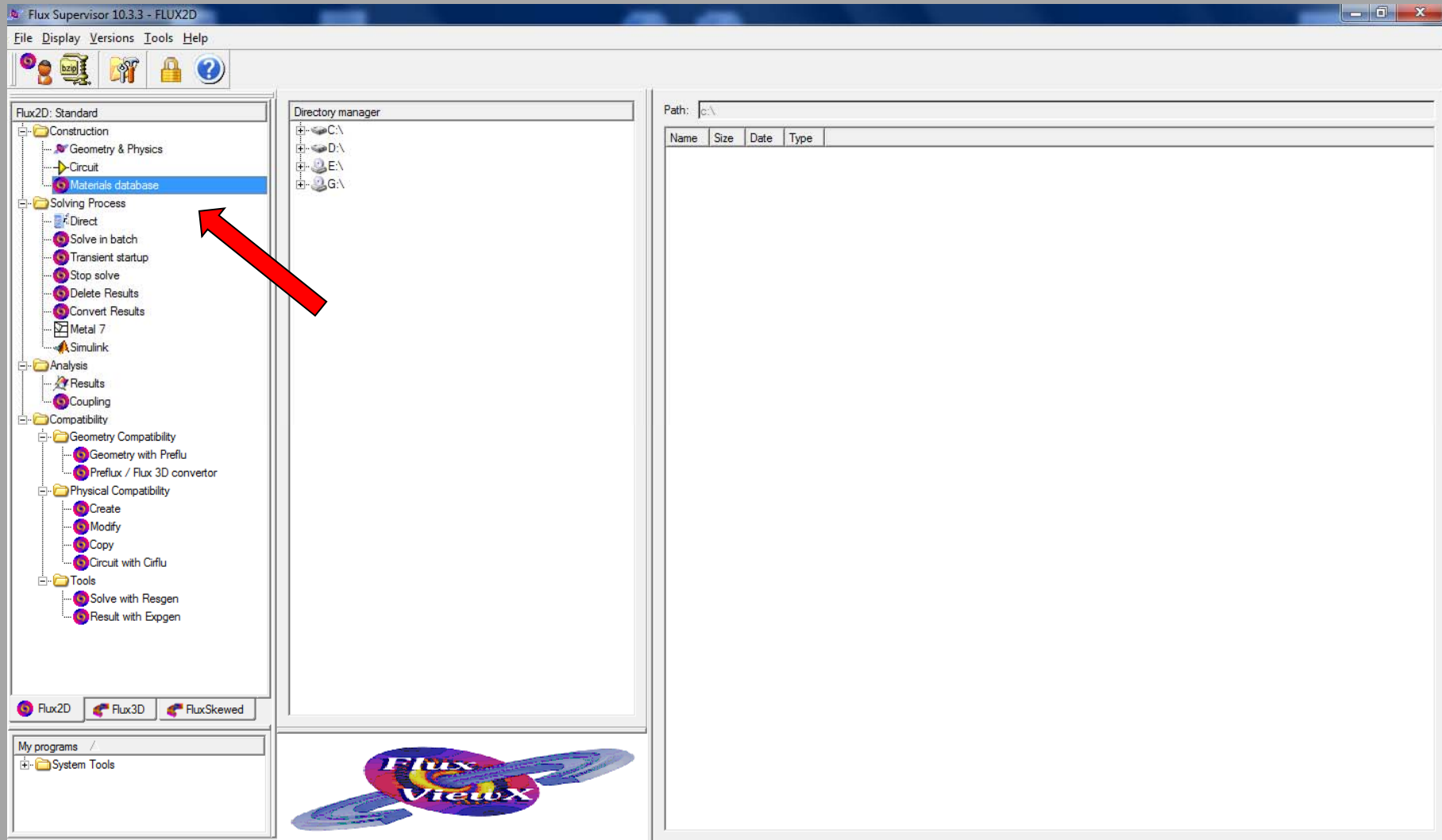


Lista de comenzi

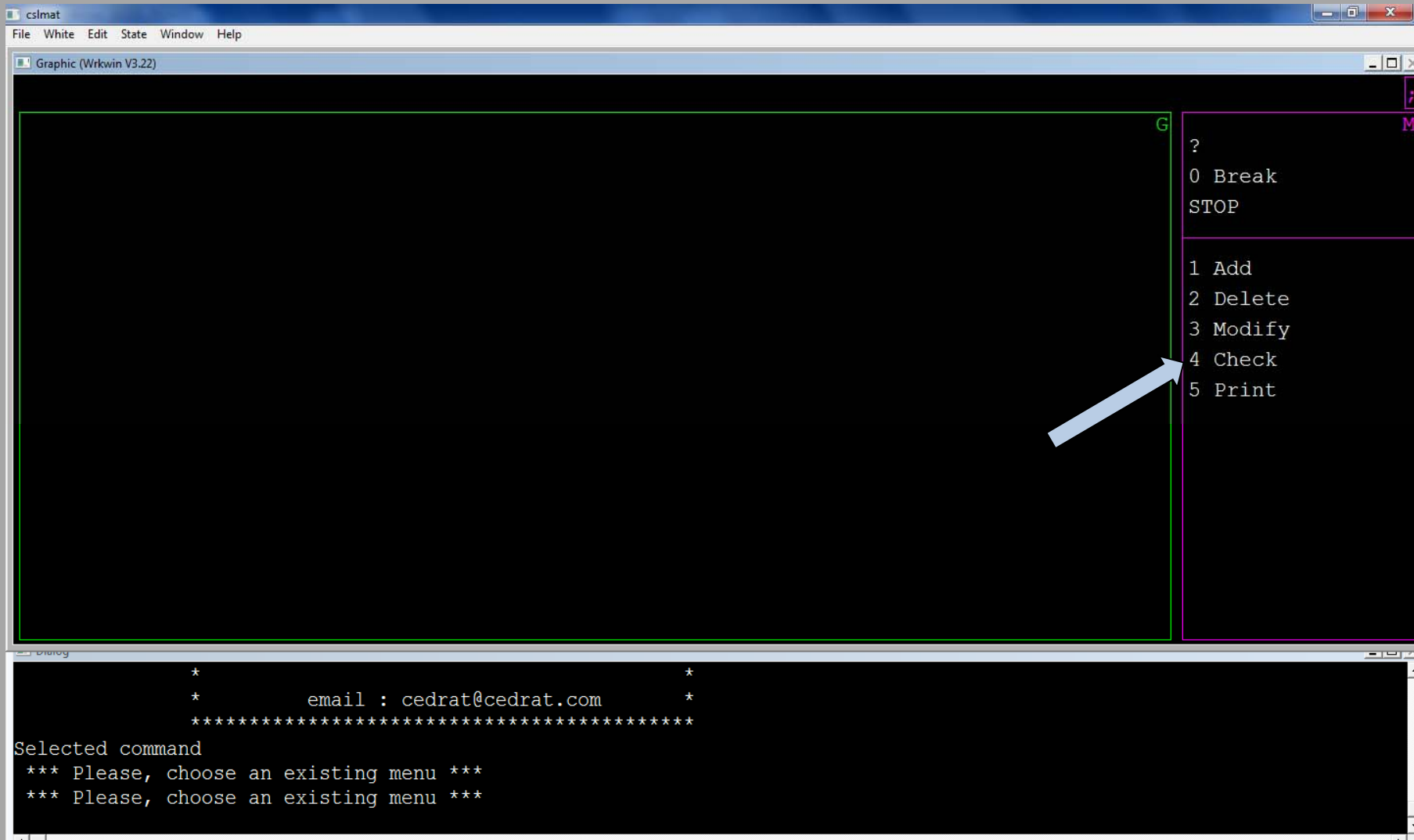
Model name	Command	
	Isotropic property	Anisotropic property
Constant	[1_scalar_cst]	[2_tensor_cst]
Complex constant	[M_cmplx_const]	-
Constant * exponential	[E_const(T)]	-
Constant + Gaussian	[7_gauss+cst]	-
Analytic saturation curve with bend adjustment	[H_B(H)_a_scal]	[I_B(H)_a_tens]
Analytic saturation curve without bend adjustment	[B_scal_a_sat]	[C_tensor_a_sat]
Spline saturation curves	[9_scalar_splin]	[A_tensor_splin]
Straight line	[3_scalar_lin]	[4_tensor_lin]
Exponential	[5_scalar_exp]	[6_tensor_exp]
Exponential + Gaussian	[8_gauss+exp]	-
Parabola + straight line	[K_Iso_parabola]	[L_Ani_parabola]
Analytic saturation * exponential	[F_sat_a(T)] [J_B(H,T)]	-
Superconductivity	[R_Supra]	-
User sub-program	[D_user_func]	-
Nodal value	[G_Nodal_values]	-



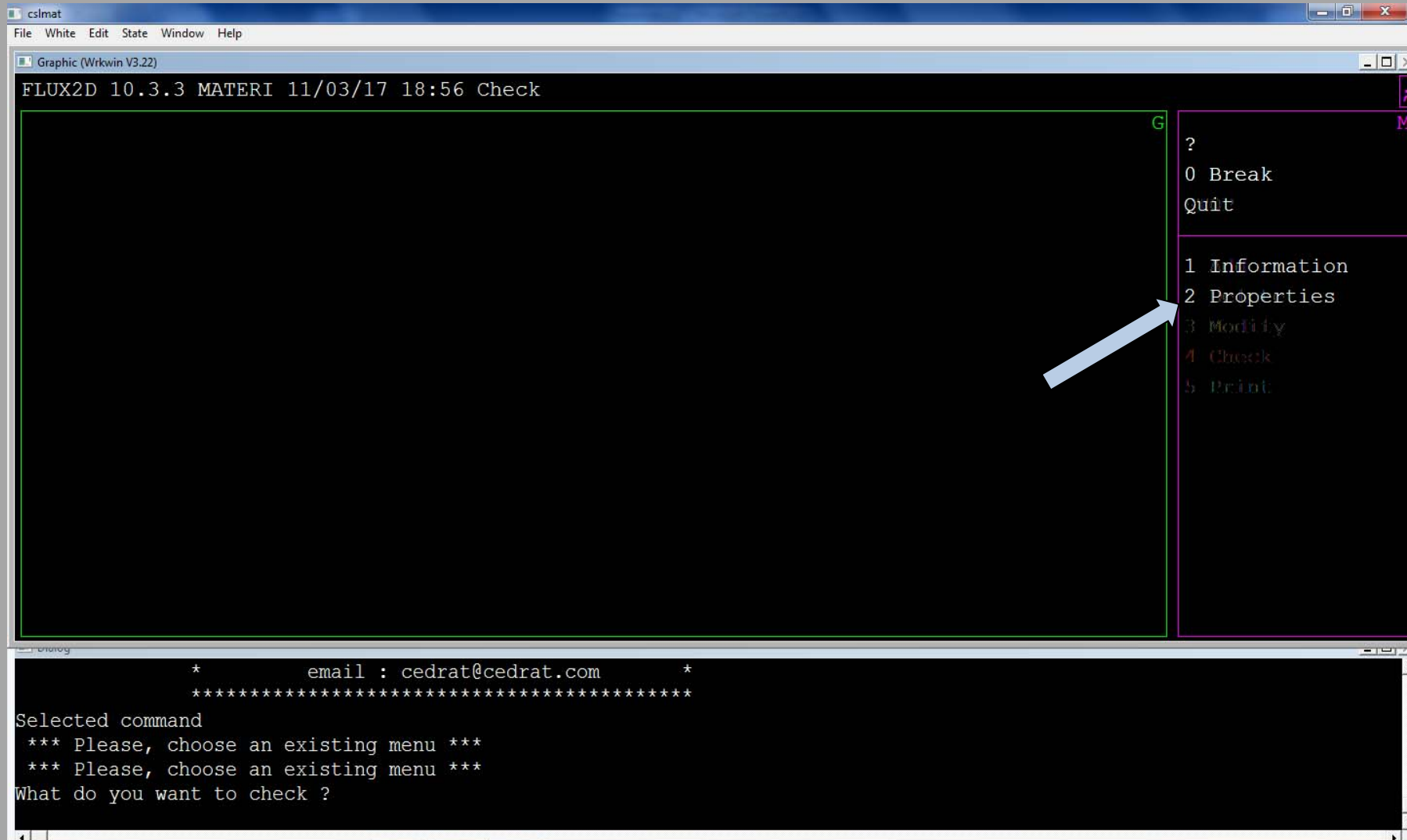
Accesarea bazei de materiale



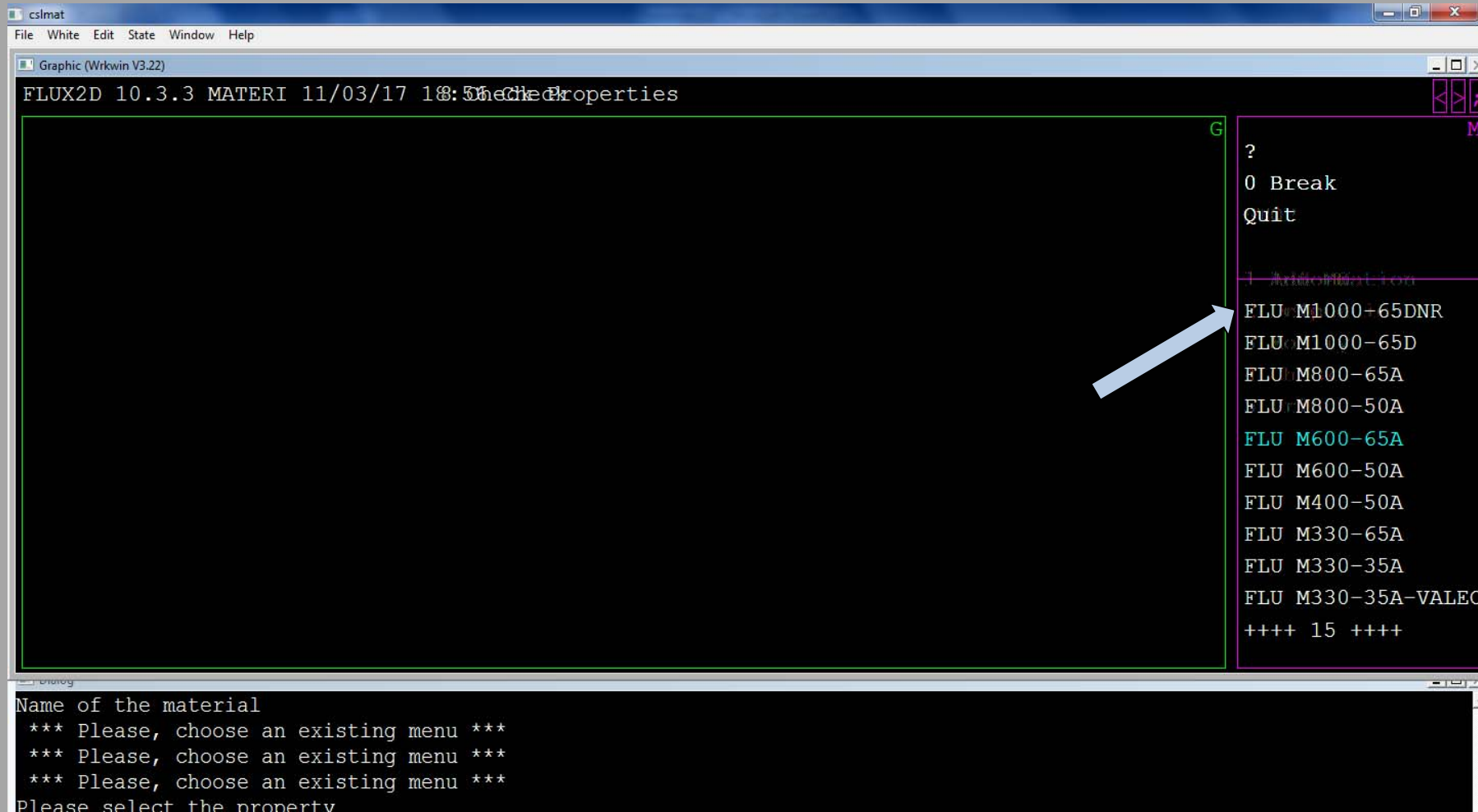
Accesarea bazei de materiale



Accesarea bazei de materiale

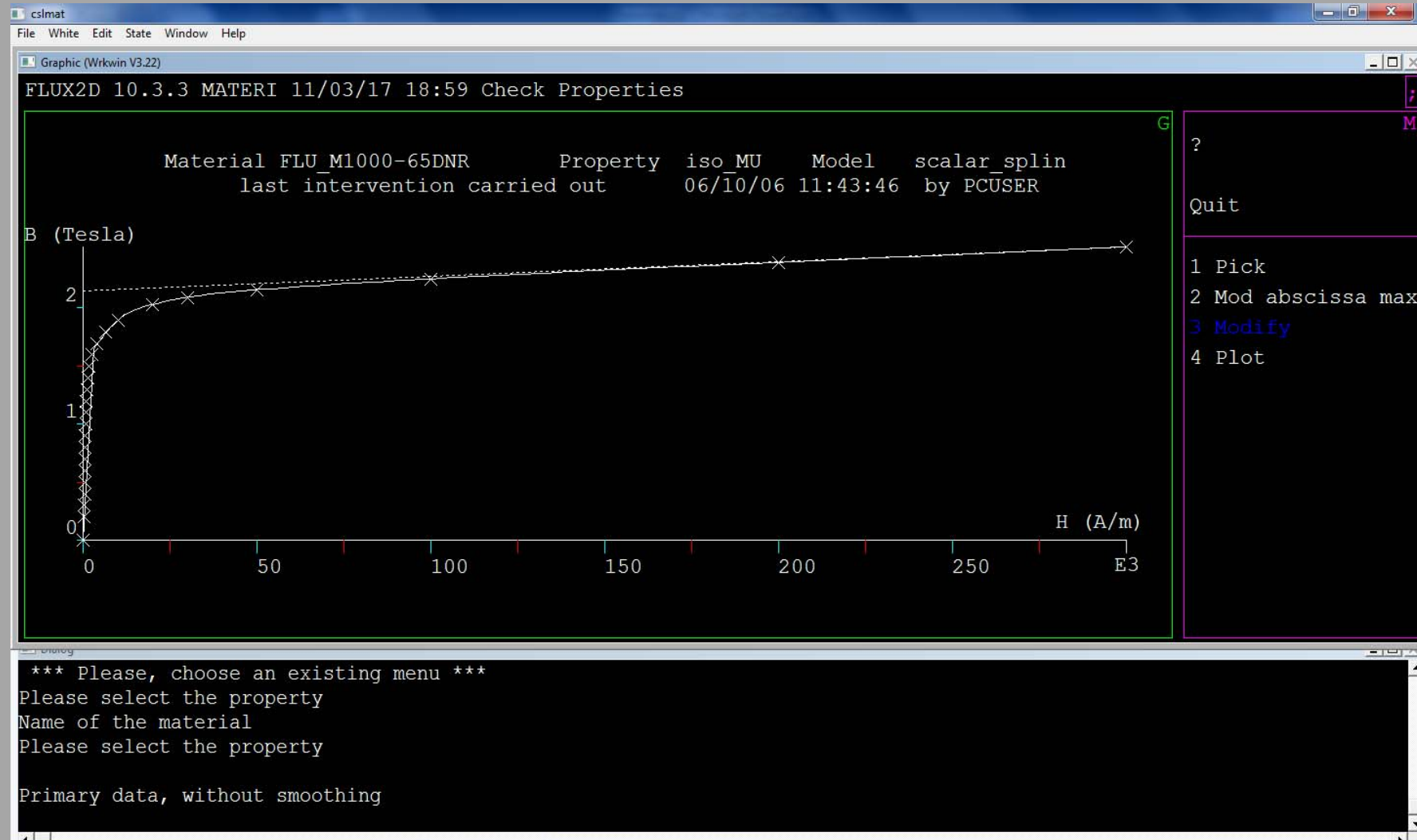


Accesarea bazei de materiale



```
csimat
File White Edit State Window Help
Graphic (Wrkwin V3.22)
FLUX2D 10.3.3 MATERI 11/03/17 18:56:06 Check Properties
?
0 Break
Quit
FLU M1000-65DNR
FLU M1000-65D
FLU M800-65A
FLU M800-50A
FLU M600-65A
FLU M600-50A
FLU M400-50A
FLU M330-65A
FLU M330-35A
FLU M330-35A-VALECO
++++ 15 +++++
Name of the material
*** Please, choose an existing menu ***
*** Please, choose an existing menu ***
*** Please, choose an existing menu ***
Please select the property
```

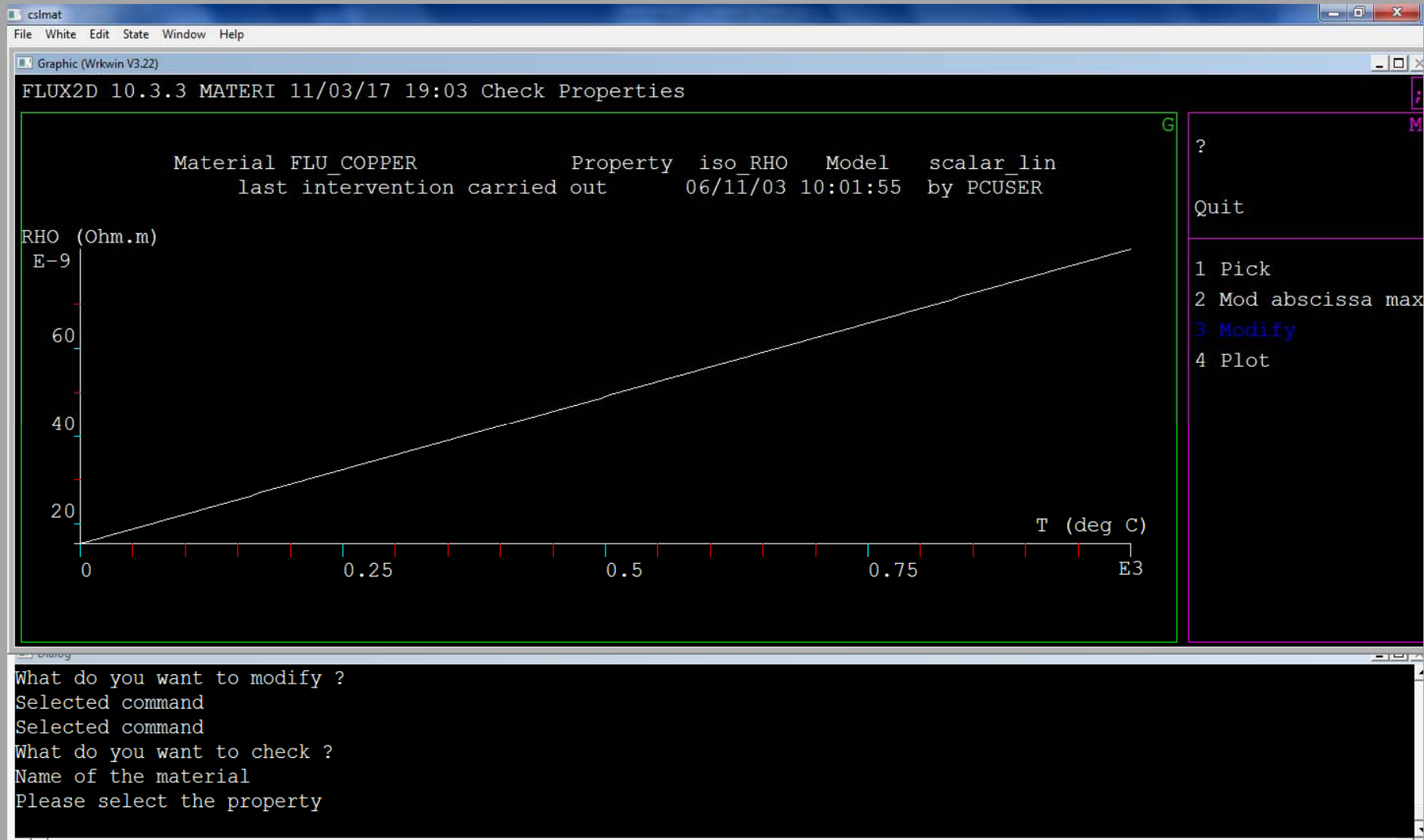

Accesarea bazei de materiale



Accesarea bazei de materiale



Accesarea bazei de materiale





CUPLAJUL CIRCUIT-CÂMP



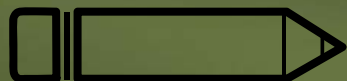
TIPURI DE ANALIZA



ANALIZA MAGNETOSTATICA



**ANALIZA
MAGNETODINAMICA**



ANALIZA TRANZITORIE



Adăugarea
circuitului electric

CUPLAJ CIRCUIT-CÂMP:

- ecuațiile circuitului electric sunt introduse în mod direct în algoritmul de rezolvare a problemei de câmp.
- ecuațiile câmpului magnetic SI ale circuitului electric sunt rezolvate SIMULTAN.

Beneficii:

- se poate introduce sistemul de alimentare (rețea sau circuit electronic);
- curentul este prezent în conductoare (spre deosebire de analiza magnetostatică unde curentul nu este individualizat pe fiecare conductor).

ANALIZA CIRCUITELOR ELECTRICE

Introducere

Un circuit electric poate conține mai multe tipuri de componente precum:

- Componente uzuale ca: surse (de tensiune sau curent), componente pasive (rezistențe, bobine, condensatoare), semiconductoare (diode, tiristoare, GTO), întrerupătoare...
- Componente specifice analizei de tip cuplaj circuit-camp: conductoare solide sau bobine (cu mai multe spire)

Descrierea componentelor

Componentele sunt caracterizate și descrise de comportarea lor electrică.

- În cazul componentelor uzuale este vorba despre caracteristica tensiune-curent, adică relația dintre tensiunea la bornele componentei și curentul ce parcurge acea componentă
- În cazul componentelor specifice este vorba despre ecuația diferențială ce leagă potențialul magnetic, potențialul electric, curentul și tensiunea

ANALIZA CIRCUITELOR ELECTRICE

Descrierea unui circuit electric (definiții):

Structura unui circuit electric este formată dintr-un ansamblu de noduri și laturi ce conțin componente electrice.















- Un nod este un punct din circuit unde se intersectează două sau mai multe laturi.
- Circuitul electric conține două sau mai multe laturi ce formează o buclă închisă (nu se pot analiza circuite deschise)

Ecuția circuitului electric

Ecuțiile ce descriu circuitele electrice se bazează pe legile lui Kirchoff.

- Legea I: suma curenților ce intră într-un nod este egală cu suma curenților ce ies din acel nod
- Legea II: Suma algebrică a tensiunilor într-o buclă de circuit este zero.

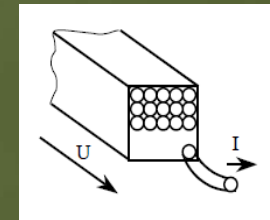
Lista componentelor electrice

Voltage/current sources	Current source 	Voltage source 		
Field - circuit coupling components	Stranded conductor 		Solid conductor 	
R, L, C components	Resistor 	Coil 	Capacitor 	
Switches and semi-conductors components	Switch 	Diode 	Thyristor 	GTO 
Rotating machine components	Brush-segment 		Squirrel cage 	
Ground				

TIPURI DE CONDUCTOARE

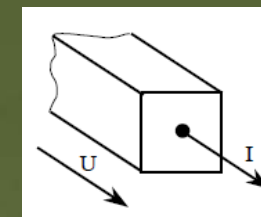
1. Conductoare cu mai multe spire („stranded conductors”)

Din punct de vedere fizic, componenta „stranded conductor” conține unul sau mai multe conductoare elementare. Diametrul conductorului este mai mic decât adâncimea de pătrundere astfel încât densitatea de curent este practic constantă în toată secțiunea conductorului.



2. Conductoare compacte (solid conductors)

Din punct de vedere fizic, componenta „solid conductor” este un conductor gros în care se manifestă curenții turbionari. Adâncimea de pătrundere are o valoare comparabilă sau mai mică decât secțiunea conductorului iar densitatea de curent NU este uniformă pe toată secțiunea transversală a conductorului.



TIPURI DE CONDUCTOARE

1. Stranded conductors

In interiorul componentei „stranded conductor” valoarea adâncimii de pătrundere este mult mai mare decât secțiunea transversala a conductoarelor. In acest caz, curentul indus in conductor este neglijabil in comparație cu cel furnizat de sursa de curent, dacă acesta există. Distribuția spațială a câmpului magnetic nu este influențată de curenții induși ceea ce permite o decuplare parțială a ecuațiilor câmpului magnetic respectiv electric. Densitatea de curent poate fi considerată constantă in toata secțiunea conductorului

2. Solid conductors

In interiorul componentei „solid conductor” apare un cuplaj intre câmpul magnetic si cel electric; apar curenți turbionari. Densitatea de curent rezultă din sumarea densității curenților datorati sursei de alimentare (dacă aceasta există) si densitatea curenților induși. Tensiunea la bornele componentei „solid conductor” rezultă din tensiunea aplicată dar si din efectul câmpului magnetic de CA asupra conductorului.

TIPURI DE CONDUCTOARE

In analiza ce implica cuplajul câmp-circuit conductoarele sunt configurate DE DOUA ORI:

- In *circuitul electric* sub forma de componente electrice („stranded conductor” sau „solid conductor”)
- In *domeniul de studiu* cu elemente finite sub forma de regiuni (tip „stranded conductor” sau „non-meshed coils” pentru 3D)

CONDUCTOARE CU MAI MULTE SPIRE (STRANDED CONDUCTORS)

Stranded conductor: relation U, I, Φ

The basic relation linking the **current I**, the **voltage U** and the **flux Φ** is given below.

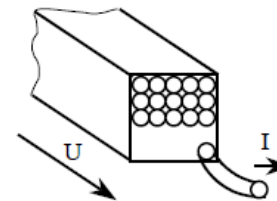
The **current** flowing through a stranded conductor component is the current **I** flowing through each strand (turn) of the correspondent coil.

The **voltage** at the terminals of a stranded conductor component is the voltage **U** at the terminals of the modelled assembly of the coil strands.

$$U(t) = R \cdot I(t) + \frac{d\Phi}{dt}$$

where:

- R is the resistance of the coil
- Φ is the flux embraced by the assembly of the coil strands



Resistance

The **resistance R** of a stranded component is equal to the resistance of the coil strands assembly:

$$R = n \cdot R_{\text{strand}} = n \cdot (\rho \cdot \ell / S_{\text{strand}})$$

The cross section of a strand is equal to:

$$S_{\text{strand}} = F \cdot S_{\text{région}} / n \text{ is the cross-section of a strand ,}$$

with :

ρ : material resistivity

ℓ : length of a strand, viz. the depth of the modeled device in 2D

F : space factor ($0 < F < 1$)

(area of the surface filled by the strands / area of the modeled region surface)

CONDUCTOARE COMPACTE (SOLID CONDUCTORS)

**Solid
conductor:
relation U, I, Φ**

The basic relation linking the **current I**, the **voltage U** and the **flux Φ** is given below.

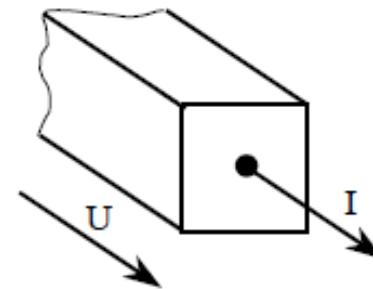
The **current** flowing through a solid conductor component is the total current **I** flowing through the correspondent solid conductor region of the finite element domain.

The **voltage** at the terminals of a solid conductor component is the voltage **U** between the front and the back faces of the modeled solid conductor region.

$$U(t) = R \cdot I(t) + \frac{d\Phi}{dt}$$

where:

- R is the resistance of the conductor
- Φ is the flux embraced by the conductor



SURSE DE ALIMENTARE

Current source: definition A current source is an ideal current source defined by the function current - time $I(t)$ that depends on the physical application, as presented in the table below.

Application	Function $I(t)$	Description in FLUX
Stedy state AC	predefined: $I(t) = I_0 e^{j(\omega t + \varphi)}$	Rms value: $(I)_{\text{eff}} = (1/\sqrt{2}) I_0$ Phase: φ
Transient	defined by the user: $I(t) = \dots$	Formula: $I(t) = \dots$

Voltage source: definition A voltage source is an ideal voltage source defined by the function voltage - time $U(t)$ that depends on the physical application, as presented in the table below.

Application	Dependence $U(t)$	Description in FLUX
Stedy state AC	predefined: $U(t) = U_0 e^{j(\omega t + \varphi)}$	Rms value: $(U)_{\text{eff}} = (1/\sqrt{2}) U_0$ Phase: φ
Transient	defined by the user: $U(t) = \dots$	Formula: $U(t) = \dots$

Concerning formulas

The formula that sets the time dependence on the current or on the voltage in a transient application is a varying one, that comprises:

- constants and varying parameters
- functions (operators, usual mathematical functions, varying functions, ...)

Example:

- $I(t) = I_0 \sin(\omega \cdot t + \varphi)$
- $U(t) = U_0 \text{trapez}(t, T_1, T_2, T_3)$

COMPONENTE PASIVE

Utilization

The passive components are used in the Steady state AC Magnetic and the Magnetic Transient applications.

Characteristic

The current-voltage characteristic for each of these different components is mentioned again in the table below.

Component	Current-voltage characteristic	Characteristic quantity	Initial value
resistor	$U(t) = R I(t)$	R is the value of the resistance in (Ω)	
coil	$U(t) = L \frac{d}{dt} I(t)$	L is the value of the coil inductance (in H)	Initial current $I(t = 0)$
capacitor	$I(t) = C \frac{d}{dt} U(t)$	C is the value of the capacitance (in F)	Initial voltage $U(t = 0)$

where:

- $U(t)$ is the voltage at the terminals of the component (in V)
- $I(t)$ is the current flowing through the component (in A)

COMUTATOARE SI SEMICONDUCTOARE

Utilization

The semi-conductor components switch, diode, thyristor, and GTO are available **only** in **transient applications**.

In fact, it deals with the commanded components, and their state (on, off) is time dependent.

Overview

In a general way the semi-conductor components are defined by:

- a current-voltage characteristic
- a command mode

Diodes, thyristors and GTOs use the same models for their current-voltage characteristic. Two models are available for this characteristic: the **Ron-Roff** model and the **Exponential** model. These two models are described in the following paragraph (§ 3.3.7).

The semi-conductors components are presented in the table below.

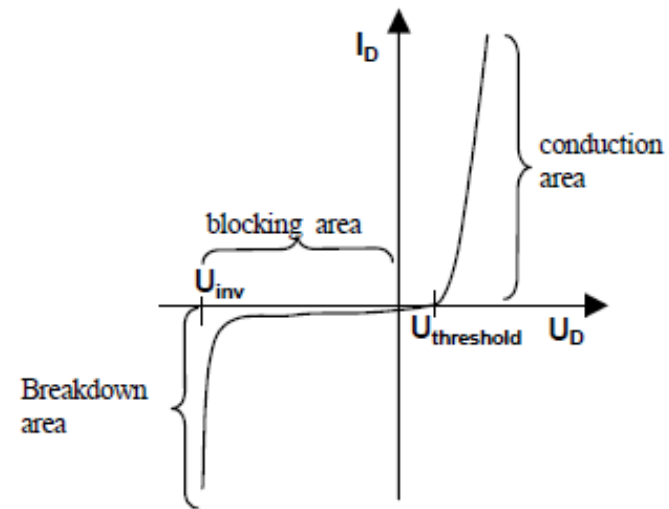
Component	Model for the current-voltage characteristic	Command mode	
		ignition	extinction
Switch	Ron-Roff	controlled	controlled
Diode	Ron-Roff / Exponential	natural	natural
Thyristor	Ron-Roff / Exponential	controlled	natural
GTO	Ron-Roff / Exponential	controlled	natural or controlled

DIODE

Diode: behavior The behavior of a diode, as well as the diode operation, can be deduced from the current-voltage characteristic:

$$I_D = f(U_D).$$

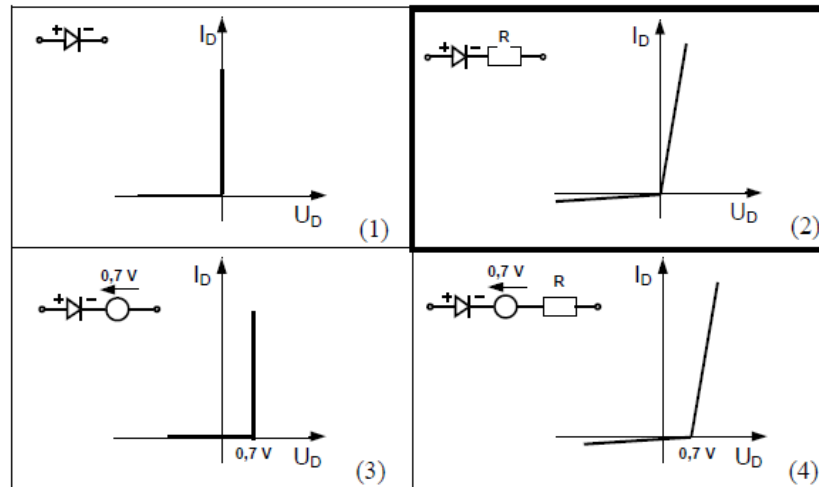
This characteristic is represented on the figure on the right.



DIODE: MODELUL - cu aproximare liniara

Linear approximation

It is often easier to consider the diode in an approximate manner. Hence the simple models in the table below are proposed.



The model Ron-Roff of FLUX

The simplest model proposed in FLUX for a diode is called the **Ron-Roff** model. It relates to model 2 in the table above.

The necessary quantities to define the $I_D = f(U_D)$ characteristic by this model are:

- the on state resistance **Ron** ; the value of this resistance should be low enough, generally of the order of $0,1\ \Omega$
- the off state resistance **Roff** ; the value of this resistance must be large enough, generally of the order of $10,000\ \Omega$

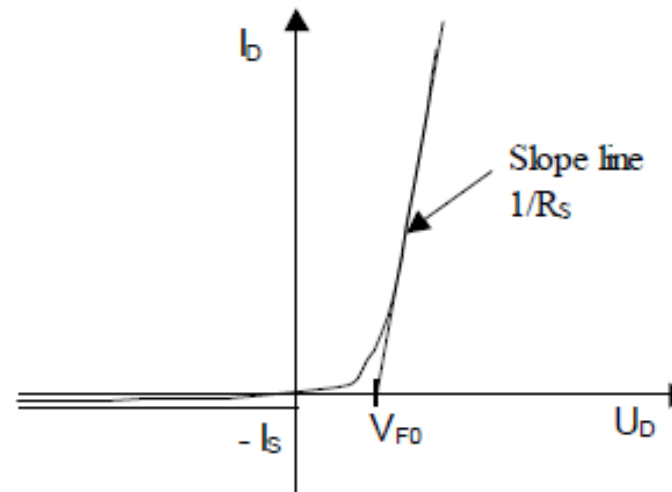
To represent a diode using model 4, it is necessary to juxtapose a FLUX component diode and a voltage source.

DIODE MODELUL - cu reprezentare exponentiala

The parameters necessary for the definition of a diode using this model are represented in the figure below.

These are:

- the knee forward voltage:
 V_{F0} (in V)
- the extrinsic resistance:
 R_S (in Ω)
(or bulk resistance)
- the saturation current:
 I_S (in A)



Typical values for these three parameters are proposed by default :

$$V_{F0} = 0.7 \text{ V} \quad R_S = 0.1 \text{ } \Omega \quad I_S = 10^{-6} \text{ A}$$

SEMNALE ELECTRICE DE COMANDA

Command signal

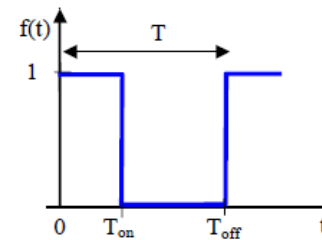
The command mode is a dependence $f(t)$ that can be a function:

- defined by the user (formula)
- crenel

Crenel function

The crenel function is a function that defines a crenel. It is presented in the figure below.

- T is the period
- T_{on} is the turn on time
- T_{off} is the turn off time

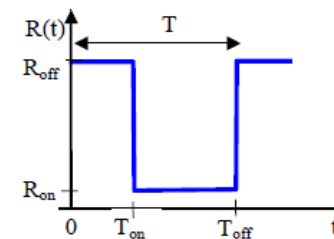


Switch example

The **Switch** component is a semi-conductor component controlled at the opening and at the closing, independent of the condition at its terminals.

An example of the $R(t)$ characteristic of a switch is presented in the figure below.

- T is the period
- T_{on} is the turn on time
- T_{off} is the turn off time
- R_{on} is the on state resistance
- R_{off} is the off state resistance



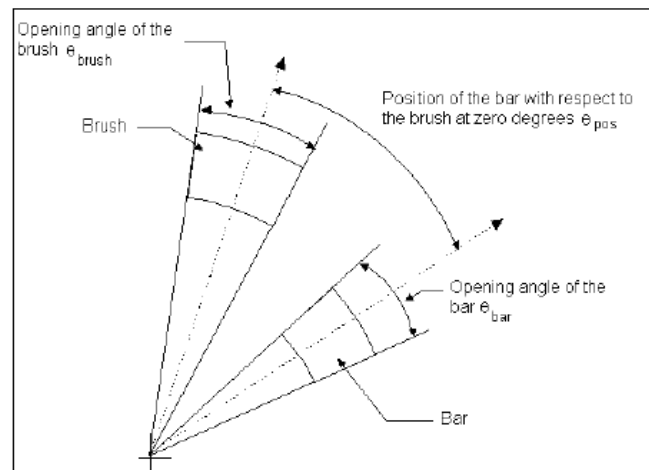
COMPONENTA „LAMELA COLECTOR-PERIE”

Brush-segment The **brush-segment component** is a switch describing the electrical contact between a segment of the commutator segment and the brush in a D.C. machine.

Utilization This component is used in transient applications and requires the use of kinematic coupling.

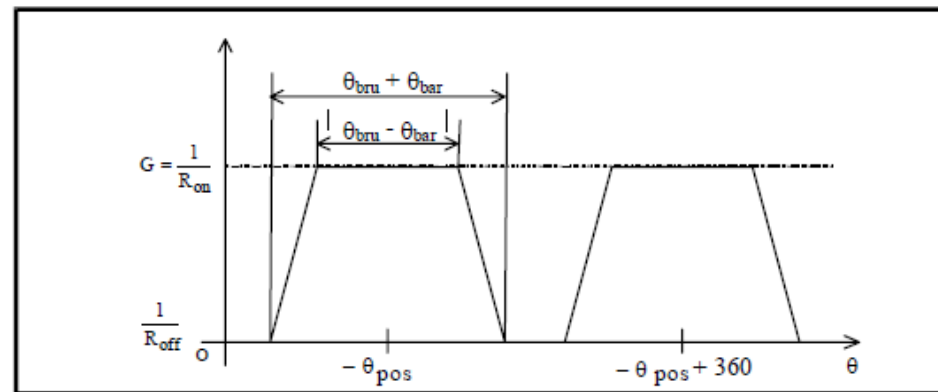
Brush-segment: characteristics The brush-segment component is characterized by five parameters:

- the on state resistance **R_{on}** in Ohms
- the off state resistance **R_{off}** in Ohms
- the angular position of the commutator segment with respect to the brush position **θ_{pos}** in degrees
- the brush opening angle **θ_{bru}** in degrees
- the opening angle of the commutator segment **θ_{bar}** in degrees



COMPONENTA „LAMELA COLECTOR-PERIE”

Brush-segment: operation Conductance of brush-segment component (negative θ_{pos}).



The brush-segment component is in full conduction whenever the mechanical angle of the rotor (θ_{mec}) is opposite to the angular position of the commutator segment with respect to the brush (θ_{pos}).

Thus, we have conduction of the brush-segment starting from $\theta_{mec} = -\theta_{pos}$

Description of a commutator To define the commutator of an electrical machine that includes N brushes and M commutator segments, it is necessary to connect each brush to the M commutator segments. Thus, it is necessary to create $N \cdot M$ brush-segments components.

COMPONENTA „COLIVIE DE VEVERITA”

Colivia de veveriță	<p>Este ansamblul de bare scurt-circuitate la capete de inele, respectiv înfășurarea rotorică a motoarelor asincrone in scurt-circuit.</p> <p>Aceasta componentă reprezintă, de fapt, o <i>macro-componenta</i>.</p>
Utilizare	<p>Această componenta este disponibilă in aplicațiile magneto-dinamice si tranzitorii.</p>

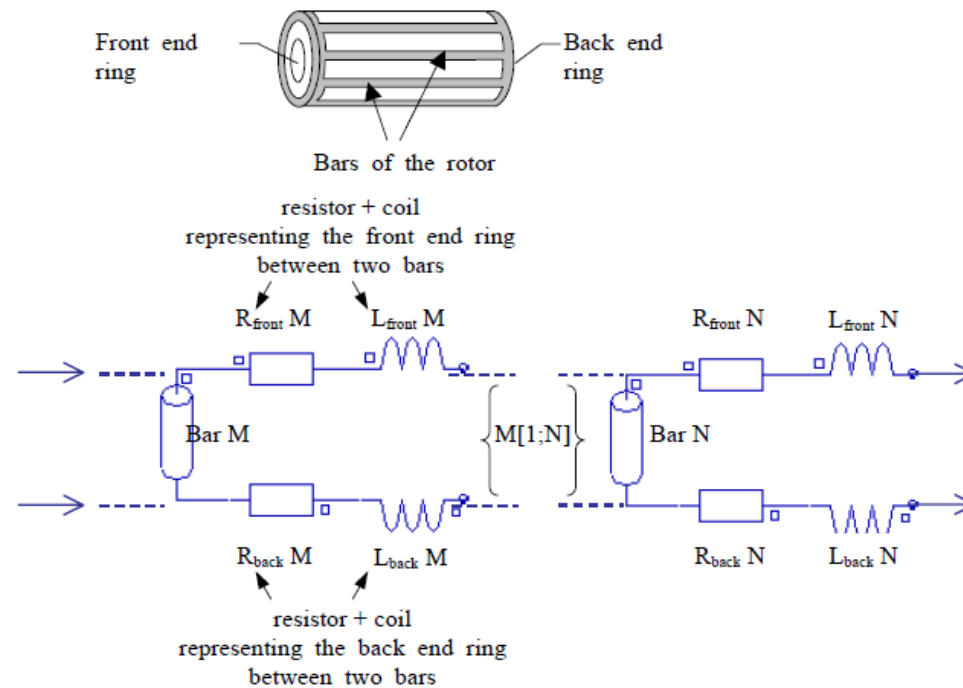
COMPONENTA „COLIVIE DE VEVERITA”

**Squirrel cage:
the electrical
circuit
components**

The **electrical circuit** of a squirrel cage contains the following components:

- a solid conductor for each rotor bar
- a resistor and a coil between either end of each of the conductors in order to simulate the end ring.

These pieces of information are represented in the figure below.



If N is the number of the bars of the squirrel cage, the electrical circuit contains N solid conductors, $2N$ resistors and $2N$ coils.

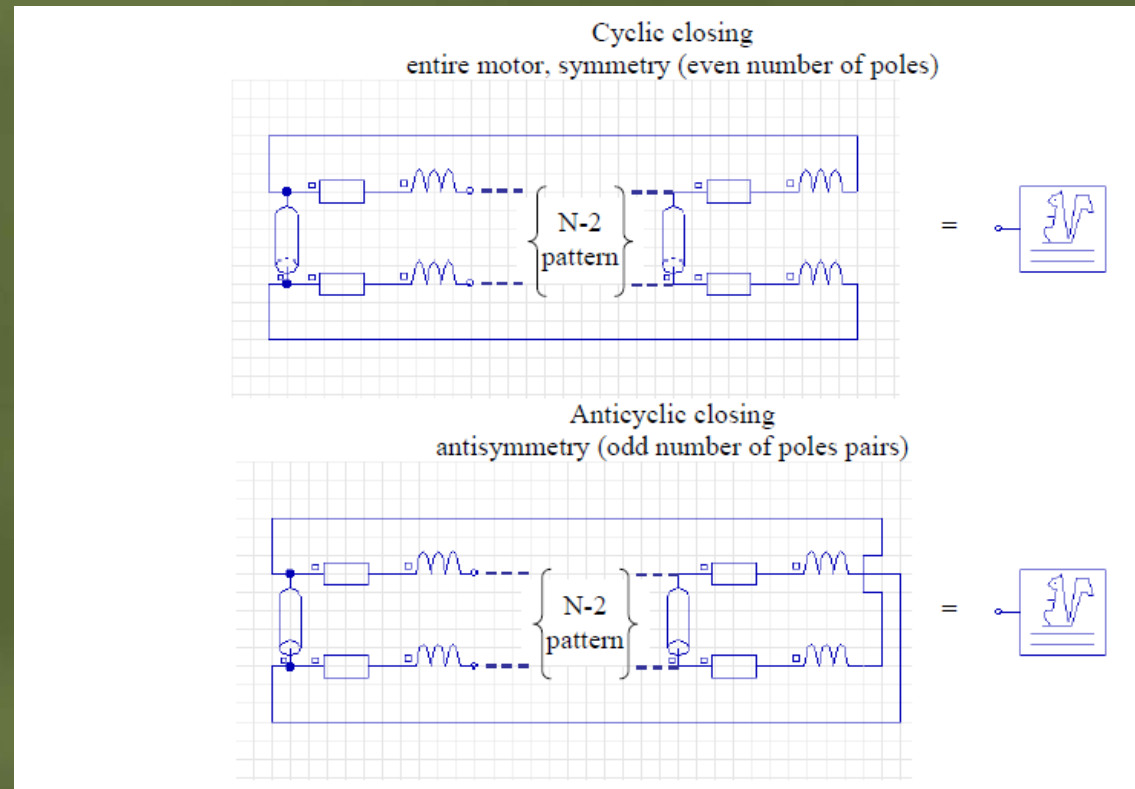
COMPONENTA „COLIVIE DE VEVERITA”

Circuitul electric al unei înfășurări în scurt-circuit se poate închide în două feluri după cum geometria mașinii este reprezentată parțial sau total.

Tipul de închidere („closing type) a coliviei de veveriță este legat de condițiile de frontieră alocate frontierelor ce corespund domeniului de studiu cu elemente finite.

- **„cycling closing” – corespunde situației când este reprezentat întregul motor sau dacă secțiunea considerată este simetrică față de regiunile adiacente (adică în domeniul de studiu este reprezentat un număr par de poli);**
- **„anticycling closing” – dacă porțiunea reprezentată este fizic asimetrică față de regiunile adiacente (când se reprezintă un număr impar de poli).**

COMPONENTA „COLIVIE DE VEVERITA”



Macrocomponenta „squirrel cage” este definită de patru parametri:

- Numărul de bare N ; trebuie sa coincidă cu numărul de bare reprezentat in geometrie.
- Rezistența R a părții din inelul de scurtcircuitare dintre două bare alăturate.
- Inductanța L a părții din inelul de scurtcircuitare dintre două bare alăturate
- Tipul de simetrie

ANALIZA CU CUPLAJ CAMP-CIRCUIT

Proiectele ce includ cuplaj câmp-circuit se realizează în același mod cu analizele din magnetostatica la care se adaugă încă două proceduri suplimentare:

	Descriere	Context
1	Realizarea schemei electrice	Modulul: Circuit
	Descrierea parțială a componentelor electrice	
2	Importarea circuitului electric în proiect	Modulul: Pre-procesor (Physical properties)
	Corelarea regiunilor domeniului de studiu cu componentele electrice din schema electrică	
	Caracterizarea completă a componentelor circuitului electric	

ANALIZA CU CUPLAJ CAMP-CIRCUIT

Operații in modulul „Circuit”	Se constituie („desenează”) schema electrica si se salvează ca fișier individual. Se definesc caracteristicile (valorile) componentelor pasive: rezistente, inductanțe si capacități.
Operații in modulul „Physical Properties”	Se realizează corelația între regiunile specifice din domeniul de studiu cu componentele circuitului electric. Componentele de circuit sunt reprezentate de doua ori: a) Odată in circuitul electric ca „stranded conductor” sau „solid conductor”. b) A doua oară, in domeniul de studiu, ca regiuni tip „stranded conductor” sau „solid conductor”. Utilizatorul trebuie să coreleze cele două tipuri de reprezentări (circuit – geometrie). Componentele de tipul surse de tensiune sau curent, precum si cele specifice (semiconductoare, componente specifice mașinilor electrice) sunt descrise in „Physical properties”.

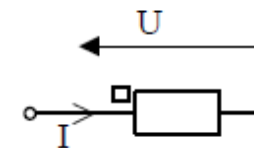
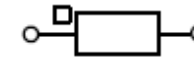
SENSUL DE PARCURGERE A COMPONENTELOR

Orientation reference: sign convention

To orient the components, we will note the presence of a mark - **square** symbol, on one of the points of the components (excepting the macro-component, squirrel cage, that has a single point).

By convention:

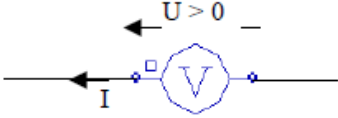
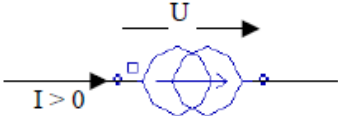
- the voltage U at the terminals of a component is given in function of the two potentials by the relationship:
$$U = V_{\text{hot point}} - V_{\text{cold point}}$$
- the current flowing through a component is positive when it enters via the hot point



SENSUL DE PARCURGERE A COMPONENTELOR

Orientation of sources

The orientation of sources defines the direction of the current through the electrical circuit.

Voltage source (with $U > 0$): the current exits via the hot point	
	<p>With the convention:</p> <ul style="list-style-type: none"> • generator : $U > 0$ and $I > 0$ • receptor : $U > 0$ and $I < 0$ (FLUX 2D)
Current source (with $I > 0$): the current enters via the hot point	
	<p>With the convention:</p> <ul style="list-style-type: none"> • generator : $I > 0$ and $U > 0$ • receptor : $I > 0$ and $U < 0$ (FLUX 2D)

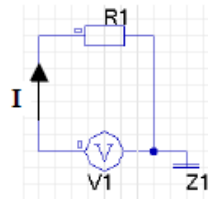
Note:

- In FLUX 2D the convention receptor is used for the components assembly (generator and receptor).
- In FLUX 3D, the convention receptor is used for the assembly of the receptor components. Concerning the generator components: the current through the voltage source, as well as the voltage in a current source, is not computed.

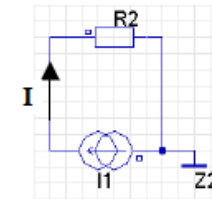
Example

Two circuit examples, with voltage source and with current source, are shown in the figure below.

Circuit with
voltage source
 $V1 > 0$



Circuit with
current source
 $I1 > 0$



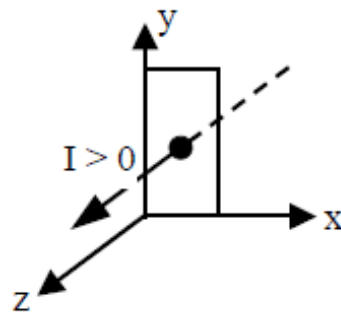
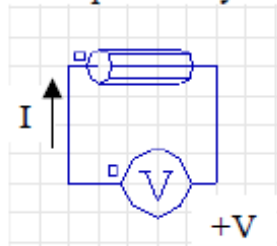
SENSUL DE PARCURGERE A COMPONENTELOR

Orientation of the conductors (2D)

The **orientation of the conductor components** in the electrical circuit defines the direction of the current in the **related regions** of the finite element domain.

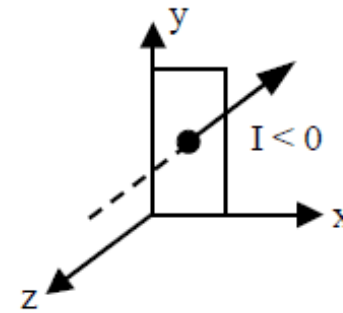
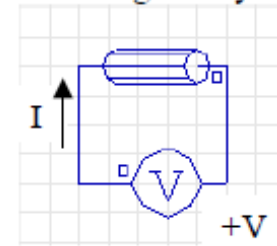
In the conducting regions of the finite element domain the current is normal to the plane of the figure.

Conductor positively oriented



I positive:
the current flows from the back
to the front of the figure

Conductor negatively oriented



I negative:
the current flows from the front
to the back of the figure

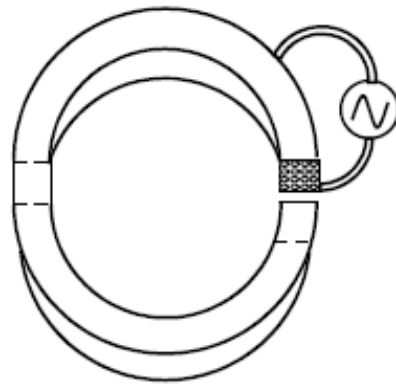
MODELAREA BOBINELOR – 2D axisymmetric

Modeling of a circular coil (axisymmetric domain)

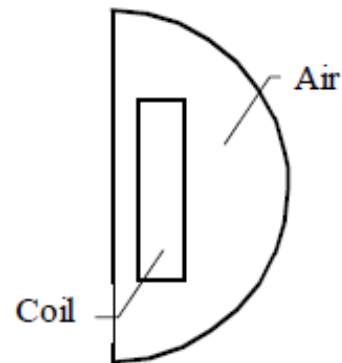
The circular coil is represented:

- in the **2D axisymmetric finite elements domain** by a region of stranded conductor type
- in the **electrical circuit** by a component of stranded conductor type

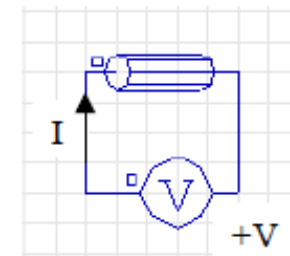
The different diagrams (real device, finite elements domain and electrical circuit) are represented in the figure below.



Real device



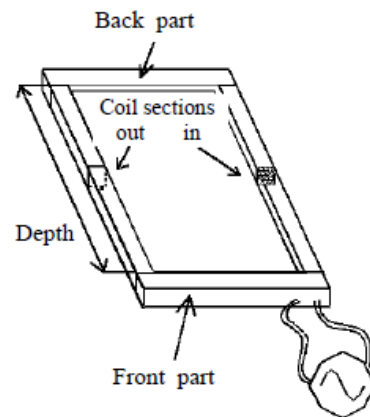
2D axisymmetric finite elements domain



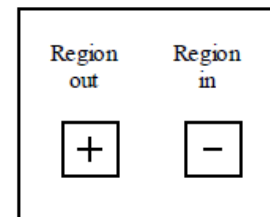
Electrical circuit

MODELAREA BOBINELOR – 2D plane

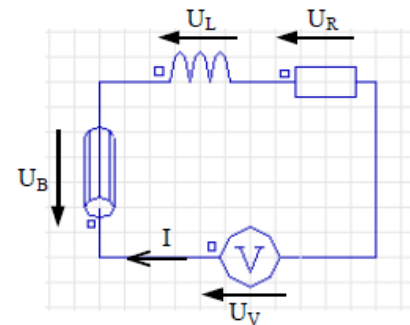
In the electrical circuit, the resistance R and the inductance L correspond to the **front** and **back** parts of the conductor (end turns, ...) that are not modeled in the finite elements domain.



Device



2D plane
finite elements domain



Electrical circuit

$$U_V = U_B + U_R + U_L$$

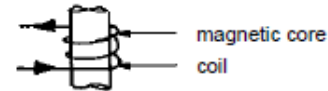
Important note:

If two components are considered to model the **out** and **in** coil sections, the two stranded conductors must be oriented in opposite directions in order that the currents in the **in** and **out** finite elements regions be opposed.

MODELAREA BOBINELOR – 2D plane

EXAMPLE 1 : a coil

- Real diagram

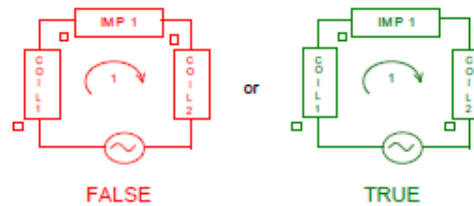


- Modelling



- Electrical diagram

2 possibilities



- Flux lines



- Defined by :

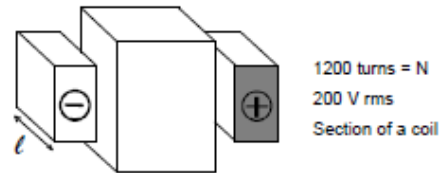
ALI | V_{ms}
PHASE

COIL 1 et 2 | Resistance
Number of turns

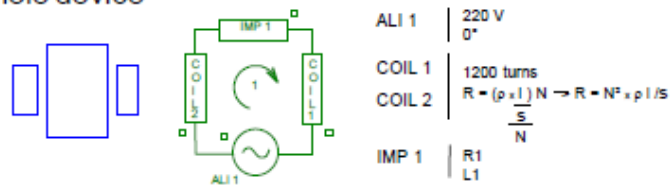
IMP 1 | Resistance
Inductance

MODELAREA BOBINELOR – 2D plane

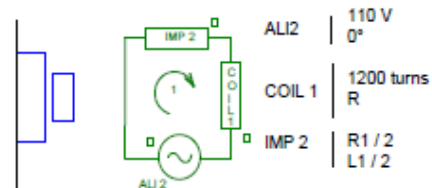
EXAMPLE 2 : A coil with symmetries in the plane



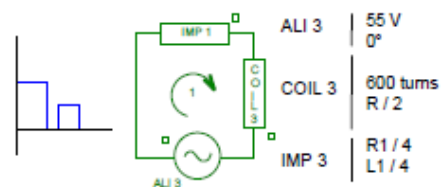
- Whole device



- Half device



- Quarter device



CONNECTAREA CIRCUITELOR

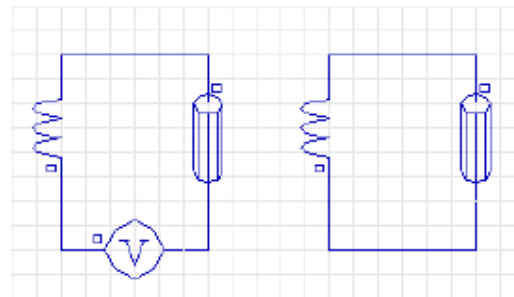
Connected circuit

A **connected circuit** is a circuit in which there is a path between any two nodes.

If the circuit is unconnected (not allowing passage from any node to any other node by a path) one must add connections.

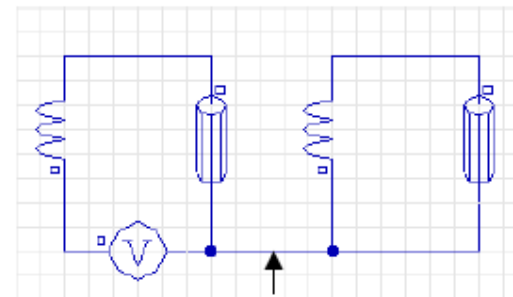
These connections bear no influence on the results.

Unconnected circuit



Two circuits

Connected circuit



Addition of a connection to obtain one electrical circuit

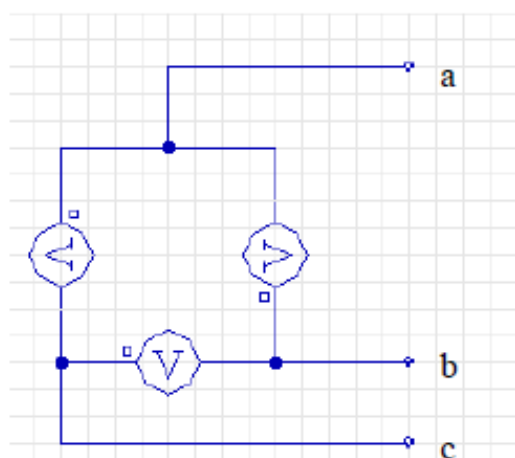
CONEXIUNEA- Δ –SURSE DE TENSIUNE

Surse de tensiune conectate in triunghi

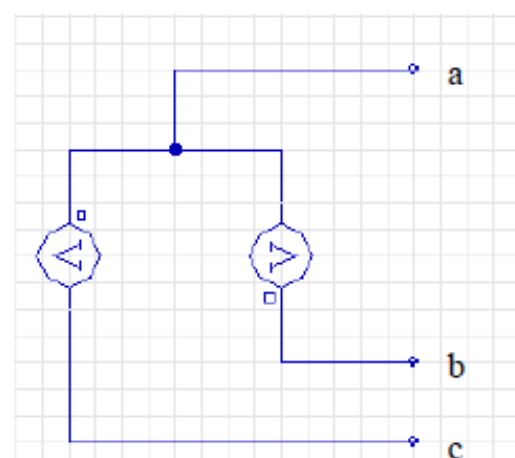
Metoda de analiza ce descrie ecuația corespunzătoare circuitului electric nu permite reprezentarea conexiunii triunghi in conexiunea reala

Soluție

**Problema se rezolvă prin eliminarea uneia dintre surse. Acest lucru va determina potențiale corecte in punctele a, b si c.
In analiza 2D, curenții prin cele doua surse ramase NU sunt reali dar bilanțul de puteri este corect.**



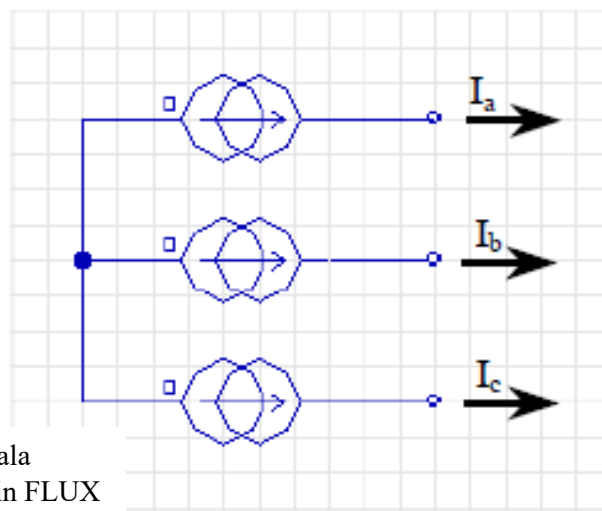
Schema reala
A NU se utiliza in FLUX



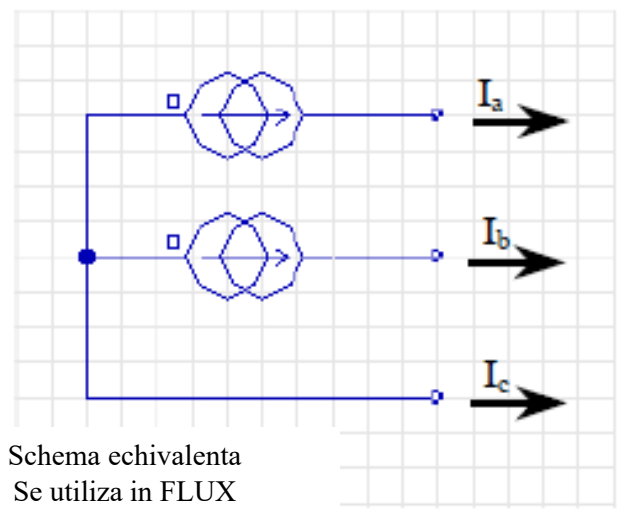
Schema echivalenta
A se utiliza in FLUX

CONEXIUNEA-Y –SURSE DE CURENT

Surse de curent conectate in stea	Metoda de analiza ce descrie ecuația corespunzătoare circuitului electric nu permite reprezentarea conexiunii stea in forma reala
Soluție	Problema se rezolvă prin eliminarea uneia dintre surse. In analiza 2D, tensiunile celor doua surse NU sunt reale dar bilanțul de puteri este corect. In analiza 3D, tensiunile din cele doua surse Nu sunt calculate



Schema reala
A NU se utiliza in FLUX



Schema echivalenta
Se utiliza in FLUX

PROCEDURI DE LUCRU

CHARACTERIZATION

CIRFLU

- Description of circuits [DESCRIBE]
- Characterization : [DEFINE]
 - resistor
 - inductor
 - capacitor
 - on state and off state resistance of switch
 - squirrel cage
 - diode
 - thyristor
 - GTO
- Validation of the circuit [VALID]
- Creation of the data base *.CIP [ANALYZE]

PROPHY

- Links regions to circuit components
- Characterization :
 - coil (number of turns, resistance)
 - source (models, values)
 - command of switches
 - initial voltage of capacitances

MODPRO

Possible to change the electric circuit
Possible to modify the values
(but not the models)

ATENȚIONARI



- **Orientați corect componentele pentru care sensul curentului este determinant**
- **Sursele: - in analiza Magnetodinamica sunt descrise de valori rms; - in analiza Tranzitorie sunt descrise de valoarea de vârf**
- **Pentru a impune un curent nul: introduceți o rezistență de valoare foarte mare (de ex. $r = 10000 \Omega$) mai degrabă decât o sursă de curent zero**
- **Pentru a impune o tensiune nula: adăugați o rezistență mică (de ex. $r = 0,000001 \Omega$)**
- **Pentru un circuit ce conține numai componente „solid conductor”: introduceți și o rezistență mică**
- **(de ex. $r < 0,01 R_{mas}$)**
- **In analiza tranzitorie: pasul de timp este prefixat. Selectați valoarea potrivită pentru aplicația studiată.**

PROCEDURI DE LUCRU

Components	Defined during the construction of the electric circuit	Defined during the coupling of the electric circuit to the regions
Squirrel cage	<ul style="list-style-type: none"> • Number of bars • Resistance of the portion of the end ring between two bars (Ω) • Inductance of the portion of the end ring between two bars (L) • Type of symmetry 	<ul style="list-style-type: none"> • Resistance of the portion of the end ring between two bars (Ω) • Inductance of the portion of the end ring between two bars (L) • Slip
Capacitor	<ul style="list-style-type: none"> • Capacitance (F) 	<ul style="list-style-type: none"> • Capacitance (F) • Initial potential at = 0 (V)
Coil conductor	<ul style="list-style-type: none"> • Identifying name 	<ul style="list-style-type: none"> • Number of turns • Resistance of the coupled FE region (Ω) • Region
Solid conductor	<ul style="list-style-type: none"> • Identifying name 	<ul style="list-style-type: none"> • Region
Diode	<ul style="list-style-type: none"> • ON state resistance (Ω) • OFF state resistance (Ω) 	<ul style="list-style-type: none"> • ON state resistance (Ω) • OFF state resistance (Ω)
Inductor	<ul style="list-style-type: none"> • Inductance (H) 	<ul style="list-style-type: none"> • Inductance (H)

PROCEDURI DE LUCRU

Switch	<ul style="list-style-type: none"> • ON state resistance (Ω) • OFF state resistance (Ω) 	<ul style="list-style-type: none"> • ON state resistance (Ω) • OFF state resistance (Ω) • Turn on time (s) • Turn off time (s) • Period (s)
Resistor	<ul style="list-style-type: none"> • Resistance (Ω) 	<ul style="list-style-type: none"> • Resistance (Ω)
Current source	<ul style="list-style-type: none"> • Identifying name 	<ul style="list-style-type: none"> • Model, values (I)
Voltage source	<ul style="list-style-type: none"> • Identifying name 	<ul style="list-style-type: none"> • Model, values (V)
Thyristor	<ul style="list-style-type: none"> • ON state resistance (Ω) • OFF state resistance (Ω) 	<ul style="list-style-type: none"> • ON state resistance (Ω) • OFF state resistance (Ω) • Period (s) • Turn on time (s) • Trigger duration time (s) • Maximum reverse breakdown voltage (V)
GTO.	<ul style="list-style-type: none"> • ON state resistance (Ω) • OFF state resistance (Ω) 	<ul style="list-style-type: none"> • ON state resistance (Ω) • OFF state resistance (Ω) • Period (s) • Turn on time (s) • Trigger duration time (s) • Maximum reverse breakdown voltage (V) • Turn off time (s)

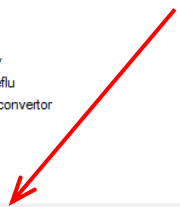
File Display Versions Tools Help



Flux2D: Standard

- Solving Process
 - Direct
 - Solve in batch
 - Transient startup
 - Stop solve
 - Delete Results
 - Convert Results
 - Metal 7
 - Simulink
- Analysis
 - Results
 - Coupling
- Compatibility
 - Geometry Compatibility
 - Geometry with Preflu
 - Preflux / Flux 3D convertor
 - Physical Compatibility
 - Create
 - Modify
 - Copy
 - Circuit with Cirflu
- Tools
 - Solve with Resgen
 - Result with Expgen

Flux2D Flux3D FluxSkewed

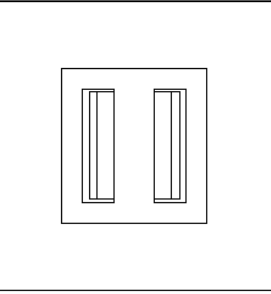


Directory manager

- C:\
- D:\
- Acreditare - SE-2013-final
- Acreditare IAD+EPAE 2013
- Curs FEME-engleza
- Dorina-jocuri
- download
- Email-Ness
- Flux
 - Flux
 - FluxFiles
 - TrifanCristian
- G
- Gifuri
- InTECH-Capitol carte
- kituri - nu sterge
- Laptop Ness
- LEONARD
- Manualul procedurilor-examinare
- PROELECTRIC II
- SopCast

Path: D:\Flux\TrifanCristian\WEEK2.TRA

Name	Size	Date	Type
PH-WEEK3.TRA	127 KB	19.03.2014	Main file: Solved
PHYSICAL-WEEK2.TRA	319 KB	13.03.2014	Main file: Solved
WEEK2.FBD	20 KB	19.03.2014	Old geometry
WEEK2.TRA	112 KB	19.03.2014	Main file: Meshed
WEEK5.FBD	12 KB	20.03.2014	Old geometry



Version : Standard

Physical memory : 2317 MB / 4092 MB

Disk D : 35442.8 MB / 99999 MB

CUPLAJUL CINEMATIC



DEFINIREA PROBLEMEI

Introducere

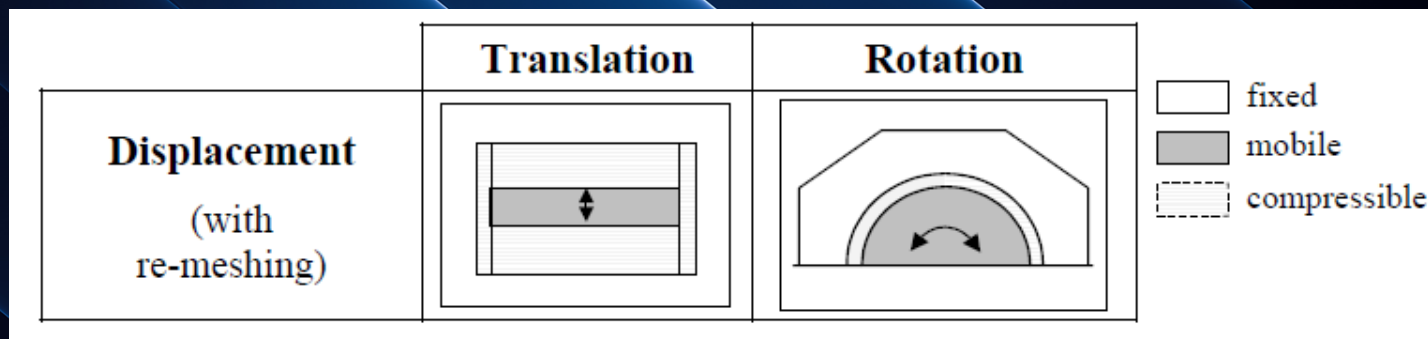
Modulul cinematic permite studiul deplasării părților mobile a unui dispozitiv datorită forțelor mecanice (elasticitate, frecare gravitație...) sau/si forțelor electromagnetice (generate de magneți permanenți sau bobine parcurse de curent).
Practic, în această situație, este vorba despre un cuplaj magneto-mecanic.

Acest tip de abordare este util pentru studiul modelului numeric al unor dispozitive precum mașinile electrice, electrovalvele, contactoare electromagnetice, etc.



In modulul de analiză 2D, studiul mișcării se poate face astfel:

- pentru mișcare de translație NUMAI de-a lungul axei Y
- pentru mișcare de rotație NUMAI in jurul axei Z



Tehnica folosită in programul FLUX este cea de „deplasare cu refacere a mesh-ului”, ceea ce presupune, IN MOD OBLIGATORIU, că partea fixă este separată de partea mobilă printr-o zonă de aer.

Analiza de tip magneto-mecanic ia in considerație atât fenomenul electromagnetic cât și ecuațiile de mișcare. Fenomenul electro-magnetic este caracterizat de ecuațiile lui Maxwell iar ecuațiile de mișcare corespund translației și rotației.

Ecuațiile câmpului electromagnetic

$$\operatorname{rot} \bar{E} = -\frac{\partial \bar{B}}{\partial t} \quad \operatorname{rot} \bar{H} = \bar{J} \quad \operatorname{div} \bar{B} = 0$$

$$\bar{B} = \mu_0 \cdot \mu_r \cdot \bar{H} + \bar{B}_r \quad \bar{J} = \tau \cdot \bar{E} \quad \operatorname{div} \bar{J} = 0$$

Ecuațiile mișcării de translație

$$m \frac{\partial^2 y}{\partial t^2} = \sum \bar{F}_{ext} \quad \longrightarrow \quad ma = F_{em} - F_r$$

unde: m=masa corpului aflat in mișcare; y=coordonata spațială; a=acclerația; F_{em} =forța electromagnetică; F_r =forța mecanică rezistentă.

Ecuațiile mișcării de rotație

$$J \frac{\partial^2 \theta}{\partial t^2} = \sum \bar{M}_{ext} \quad \longrightarrow \quad J\ddot{\theta} = M_{em} - M_r$$

unde: J=momentul de inerție al corpului aflat in mișcare de rotație; θ =coordonata unghiulară; $\ddot{\theta}$ =acclerația unghiulară; M_{em} =cuplul electromagnetic; M_r =cuplul rezistent.

Rezolvarea unei probleme de cuplaj cinematic urmează o procedură în patru pași. Pentru fiecare pas în parte, mai întâi este rezolvată problema electromagnetică și apoi cea cinematică.

1

Rezolvarea ecuațiilor lui Maxwell și determinarea forței sau cuplului electromagnetic ce acționează asupra părții mobile pentru o anumită poziție a acesteia față de partea fixă.

2

Rezolvarea ecuațiilor de mișcare; calcularea accelerației și vitezei părții mobile pe durata unui pas de timp; determinarea noii poziții a părții mobile pentru următorul pas de timp.

3

Mutarea părții mobile pe noua poziție și (dacă este necesar) refacerea structurii de discretizare (mesh) a zonei de aer.

4

Reîntoarcerea la pasul 1 pentru următorul ciclu de calcul (corespunzător următorului pas de timp).

Forța sau cuplul mecanic ce acționează asupra părții mobile reprezintă valori de intrare, furnizate de către utilizator.



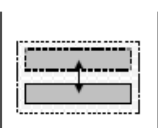
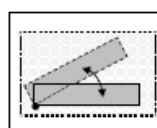
4.2.2. Re-meshing techniques: general presentation

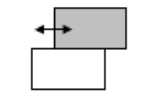

Introduction The displacement of the **moving part** determines the modification of the geometry of the modeled device. Consequently, the computation domain must be re-meshed at each time step.

In fact, the re-meshing is necessary if there is an air area (known as compressible) between the fixed part and the moving part. If the parts slip one compared to the other (and if there is no air area between the two), the re-meshing is not necessary.

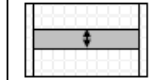
The different techniques of motion treatment (from a geometry and mesh point of view) are presented summarily in this paragraph and are detailed in the following paragraphs.


Motion (in 3D) The different situations are gathered in the table below.

Displacement in a compressible air area		
Translation	Rotation	Technique
		separation of fixed / mobile and compressible part re-meshing of the compressible area non-conforming mesh authorized at the level of the dissociation surfaces

Sliding motion along a sliding surface		
Translation	Rotation	Technique
		separation of fixed and mobile part non-conforming mesh authorized at the level of the sliding surfaces

Motion (in 2D) The different situations are gathered in the table below.

Translation displacement with translating air gap	
	re-meshing of the compressible area specific constraints on the mesh for the compressible area

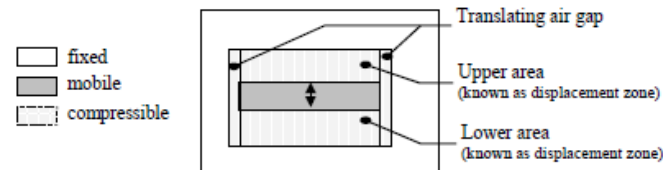
Rotation displacement with rotating air gap	
	re-meshing of the compressible area specific constraints on the mesh for the compressible area

4.2.5. Geometry and mesh / with translating air gap (2D)

Introduction This paragraph deals with translation motion with translating air gap in 2D.

Geometric point of view From a **geometric** point of view, the compressible air area is cut out in two distinct regions (see figure below):

- two lateral bands on both sides of the moving part
- two zones above and below the moving part

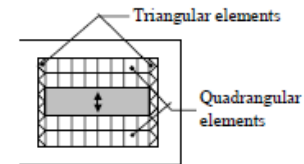


Mesh point of view From a **mesh** point of view, the compressible air area is meshed in a different way in the two distinct regions (see figure below):

- triangular elements in the lateral bands (translating air gap)
- quadrangular elements in the upper and lower areas

Some mesh rules:

- only one layer of triangular elements (lateral band)
- the same number of quadrangular elements in the length direction (upper / lower areas)



Technique used The technique used consists in **re-meshing the compressible area**. With regard to the **compressible area**:

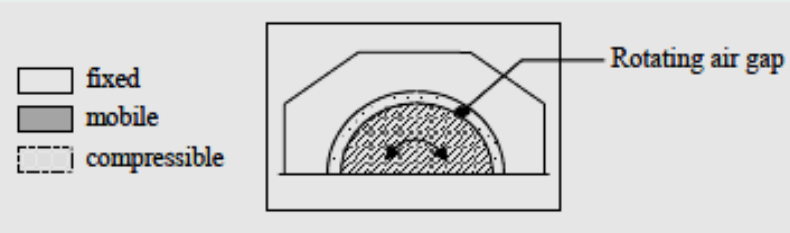
- the elements of the lateral bands (translating air gap) are **rebuilt**
- the elements of the upper and lower areas are: either **distorted** or **transferred**, according to the criteria presented in the table below.

if small displacement of the moving part (lower than the half height of an element)	if great displacement of the moving part (higher than the half height of an element)
<p>Flattened elements</p> <p>Widened elements</p> <p>... the elements are distorted</p>	<p>Removed elements</p> <p>Added elements</p> <p>... the elements are transferred</p>

GEOMETRIA SI STRUCTURA DE DISCRETIZARE (MESH) PENTRU MISCARE CIRCULARA

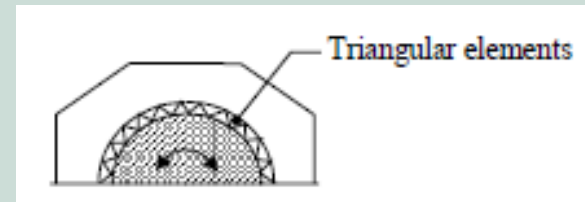
Geometrie

Din punct de vedere geometric, intre partea fixă si partea mobilă (stator-rotor) trebuie să existe o bandă de aer – „compressible area” – ale cărei frontiere reprezintă două cercuri concentrice.



Mesh

Din punctul de vedere al structurii de discretizare (mesh), această zonă conține UN SIGUR STRAT de elemente triunghiulare – „rotating air gap”.



Procedura

Procedura constă in refacerea structurii de discretizare in zona compresibilă de aer (in întrefier).

DESCRIEREA PROBLEMEI IN "FLUX"

1

Definirea părții fixe, a părții mobile și a zonei de aer - compresibilă.

2

Definirea tipului de mișcare: translație sau rotație.

3

Definirea caracteristicilor cinematice: masa sau momentul de inerție a părții mobile; mărimea forței sau a cuplului rezistent, etc.

„MECHANICAL SET”

Definiție

„Mechanical set” reprezintă un set de regiuni (ce poate îngloba și bobine) care au aceleași caracteristici de „mișcare”: fixe, mobile sau compresibile.

Un „mechanical set” de tipul	Include regiuni ce corespund
fix	părților fixe
in mișcare	părților mobile
compresibil	regiunii de aer în care partea mobilă se deplasează

Procedura

Pentru a descrie „mișcarea” în domeniul de studiu, regiunile cu același tip de „deplasare” (fix mobil sau compresibil) TREBUIE ALOCATE unui „mechanical set”.

Tipul de deplasare

- Translație de-a lungul axei Y
- Rotație în jurul axei Z

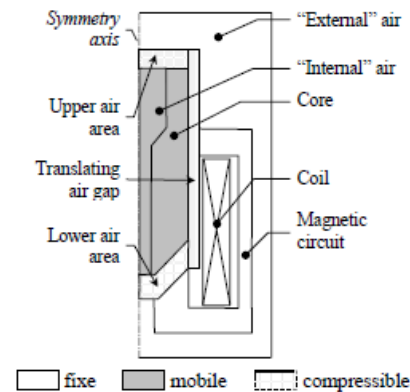
4.3.4. Translation with translating air gap (2D)

Introduction This paragraph deals with translation motion with translating air gap in 2D.

Example: presentation The example, presented in this paragraph, is drawn from Tutorial "2D Translating Motion". It deals with a cylindrical electromagnet with conical air gap.

Assignment of regions The assignment of regions in mechanical sets is done in the following way:

- **mobile mechanical set:**
 - the core
 - the "internal" air area
- **fixed mechanical set:**
 - the magnetic circuit
 - the coil
 - the "external" air area
- **compressible mechanical set:**
 - the upper air area (known as displacement zone)
 - the lower air area (known as displacement zone)
 - the translating air gap



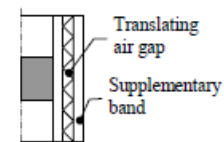
Restriction Any **contact** between the moving part (the core) and the fixed part (the magnetic circuit) is **not allowed**.

Mechanical stops For translating motion the user must make sure that contact between the fixed and moving parts will **not** occur.

To overcome the problem of contact, it is possible to define **mechanical stops** in order to prevent motion within certain areas.

Design rule The translating air gap is located at the interface between the fixed and the moving parts. If the mesh of these regions is locally refined, it will impose a number of nodes on the external lines of the translating air gap; it can be then difficult to adjust the mesh in the translating air gap (See following blocks).

To overcome mesh constraints related to the external parts, usually it is best to built an independent translating air gap between the moving and the fixed parts.



Additional mesh rules

Besides the usual mesh rules, some additional rules must be respected for the mesh of the compressible air area:

- The **translating air gap** should contain only one layer of triangular elements in its thickness, and these elements should have a shape as close as possible to an equilateral triangle.
- The **displacement areas** (two distinct areas) should be meshed with quadrangular elements. There must be the same number of elements across the width of the displacement areas.

Displacement at constant velocity: mesh advices

When the **moving part moves at a constant velocity**, the translating air gap should be **meshed evenly**, depending on the displacement at each time step. The mesh of the translating air gap is thus identical at each time step, one node replacing another node.

In this way, we avoid possible *mesh noise* that can be reflected in the computation of the global quantities: force, etc.

Thus, one should adjust the mesh on the translating air gap according to the following rules:

- adjust the number of nodes on the edges of the translating air gap so that the size of the triangle's edge corresponds to the displacement of the mobile part over a time step:

$$\Delta d = v \cdot \Delta t$$

where:

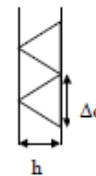
- Δd is the value of the triangle's edge,
- v is the displacement velocity
- Δt is the value of the time step

- modify the thickness of the translating air gap so that the triangles are equilateral:

$$h = \sqrt{3}/2 \cdot \Delta d$$

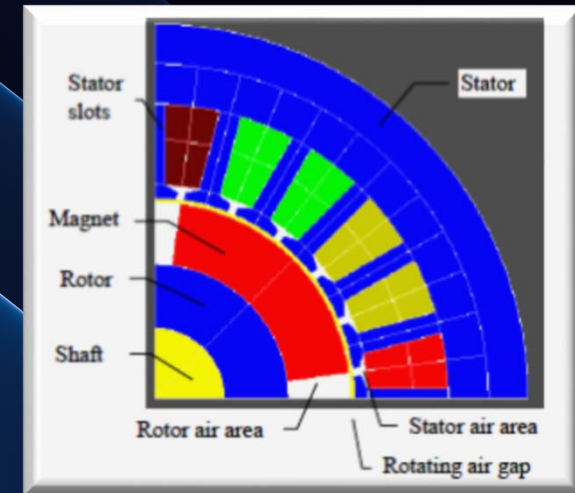
where:

- h is the triangle height
- Δd is the value of the triangle's edge.

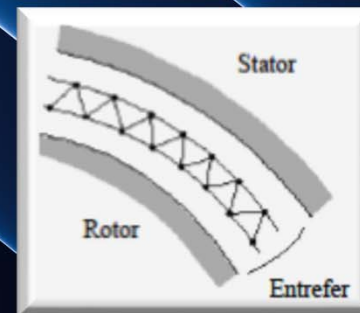


EXEMPLU ALOCARE „MECHANICAL SET”

- „mobile mechanical set” : rotor + ax + magnet permanent + zona aer între magneți permanenți;
- „fixed mechanical part”: stator + creștături statorice + istmuri creștături statorice;
- „compressible mechanical set”: întrefier.

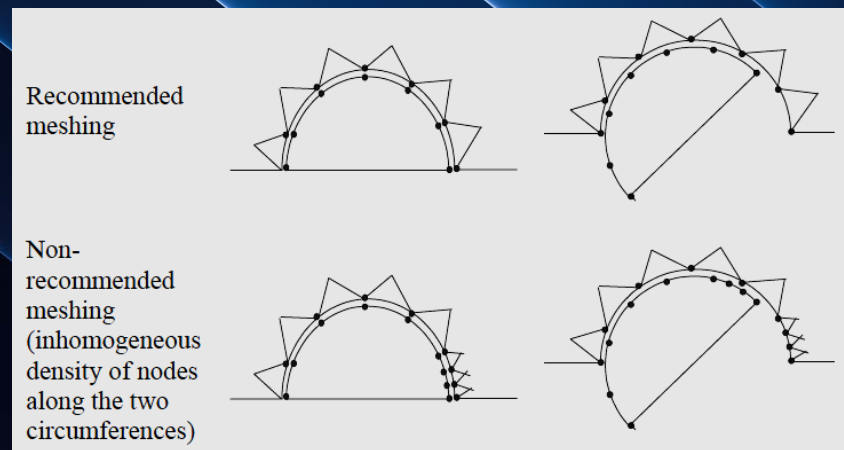


La analiza de tip tranzitoriu, unde poziția părții mobile (rotor) se schimbă față de partea fixă (stator) și se utilizează tehnica de refacere a „mesh-ului”, se poate folosi tehnica realizării unei zone compresibile mai înguste (dar în interiorul benzii de aer). Se evită în acest fel posibile erori de „re-mesh” în timpul rezolvării.



REGULI DE REALIZARE A STRUCTURII DE DISCRETIZARE

- Zona de întrefier (si anume „compressible area”) trebuie să aibă un singur strat de elemente finite triunghiulare, iar acestea trebuie să fie cât mai apropiate de un triunghi echilateral.
- Când tipul de analiză presupune studiul funcționarii la viteză constantă, întrefierul trebuie discretizat uniform si in funcție de pasul de timp ales pentru analiza tranzitorie. In acest fel, după fiecare pas de calcul, întrefierul rămâne identic din punctul de vedere a nodurilor; practic, la modificarea poziției rotorului, nodurile „cad” unele peste altele. Drept urmare, așa-numitul „mesh noise” este evitat iar determinarea unor mărimi (de ex. cuplul electromagnetic) este mai precisă.



REGULI DE REALIZARE A STRUCTURII DE DISCRETIZARE

Realizarea structurii de discretizare din întrefier ar trebui să urmeze câteva reguli:

- a) Numărul de noduri de pe cele doua frontiere ale întrefierului trebuie ales in așa fel încât mărimea laturii triunghiului să corespundă deplasării determinate de pasul de timp ales.

$$r \cdot \theta = v \cdot \Delta t$$

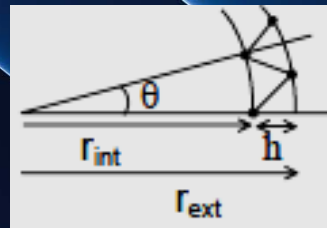
unde: $r \cdot \theta$ – valoarea laturii triunghiului ce se sprijină pe frontiera

v - viteza unghiulara

Δt – pasul de timp

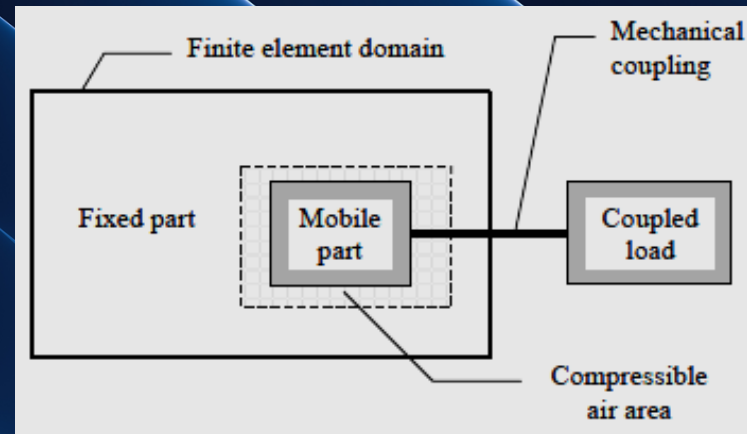
- b) Lățimea benzii din întrefier se ajustează la valoarea care permite obținerea unor elemente finite triunghiuri echilaterale.

$$h = \frac{\sqrt{3}}{2} \cdot r \cdot \theta$$



CARACTERISTICI CINEMATICE

Pentru ca ecuația cinematică să poată fi rezolvată este necesară definirea mărimilor specifice cinematice atât pentru partea mobilă (rotor) cât și pentru sarcina cuplată la axul mașinii.



Mărimile specifice cinematice sunt:

- Masa sau momentul de inerție (atât pentru partea mobilă cât și pentru sarcină);
- Forța sau cuplul rezistent ce acționează asupra părții mobile respectiv asupra sarcinii;
- Condițiile inițiale: poziția inițială și viteza inițială a părții mobile.

Forța sau cuplul rezistent pot fi exprimat prin formule predefinite pentru frecare și elasticitate („spring” force and torque).

Predefined formulas (1)

The force or the resistive torque can be described by the intermediary of a predefined formula of friction force or torque type.

(1) Friction force or torque		
Translation	Rotation	
$F_r = f_0 + f_1 \cdot \dot{y}$	$\Gamma_r = f_0 + f_1 \cdot \dot{\theta}$	in 2D
$F_r = \pm f_0 + f_1 \cdot \dot{y} \pm f_2 \cdot \dot{y}^2$	$\Gamma_r = \pm f_0 + f_1 \cdot \dot{\theta} \pm f_2 \cdot \dot{\theta}^2$	in 3D

For 3D: the signs in the equation are defined in the following way:

- if speed is positive (\dot{y} ou $\dot{\theta} > 0$) : the \pm sign is replaced by the + sign
- if speed is negative (\dot{y} ou $\dot{\theta} < 0$) : the \pm sign is replaced by the - sign

The three coefficients f_0 , f_1 and f_2 , are as follows:

- f_0 : **constant friction coefficient**, independent of speed
(in N or N.m)
- f_1 : **viscous friction coefficient**, function of speed
(in N.s/m or in N.m.s/degrees)
- f_2 : **friction coefficient**, function of speed to the second power
(in N.s²/m² or in N.m.s²/degrees²)

Caution: If there are symmetries and periodicities:

- In 2D: the coefficients f_0 , and f_1 must be defined for the part of the device represented. The forces or torques are computed for the part of the device represented.
- In 3D: the coefficients f_0 , f_1 and f_2 must be defined for the entire device, even if it is not represented entirely. The forces or torques are computed for the entire device.

Predefined formulas (2)

The force or the resistive torque can be described by the intermediary of a predefined formula of return force or torque type.

(2) Return force or torque (spring)	
Translation	Rotation
$F_r = k(y - y_0)$	$\Gamma_r = k(\theta - \theta_0)$

The coefficient k is the stiffness (or torsion) constant of the spring
(in N/m or N.m/degree).

Varying formula (3D)

The force or the resistive torque can be described by the intermediary of a varying formula (in 3D).

A varying formula is a formula function of kinematic parameters, such as position, speed, acceleration of the mechanical set considered; or a function of other mechanical sets; or a function of any varying parameters.

MODULE CINEMATICE

Pachetul de programe FLUX permite trei tipuri de analiza cinematica:

Multi-static

Funcționare
la viteza
constantă

Funcționare
in cuplaj cu
sarcina



Modul de abordare este diferit pentru fiecare in parte.

MODELUL MULTI-STATIC

- In analiza de tip multi-static se presupune că partea mobilă NU se deplasează. Calculul câmpului electromagnetic se obține pentru diverse poziții relative ale părții mobile față de partea fixă.
- Tipul de rezolvare este magneto-static ($\delta/\delta t = 0$ in ecuațiile lui Maxwell) iar ecuația de mișcare NU este luată in considerare. Modelul este echivalent cu unul de tip parametric in care poziția părții mobile reprezintă parametrul variabil.
- Procedura de rezolvare constă într-o serie de rezolvări magneto-statice pentru poziții diferite ale părții mobile.

MODELUL „FUNCȚIONARE LA VITEZA CONSTANTA”

- Acest model presupune deplasarea cu viteză constantă a părții mobile față de partea fixă.
- Calculul câmpului electromagnetic se realizează pentru fiecare pas de timp luându-se în considerare schimbarea poziției părții mobile față de partea fixă, corespunzător vitezei impuse și pasului de timp considerat. Nici în acest tip de rezolvare, ecuațiile cinematice NU sunt luate în calcul.
- Acest tip de rezolvare poate fi realizat în modulul Transient Magnetic. La rezolvarea ecuațiilor lui Maxwell se consideră câmpul magnetic variabil în timp ($\delta/\delta t \neq 0$).
- Pentru rezolvare se folosește ca parametru intermediar timpul sau poziția.

MODELUL „FUNCȚIONARE ÎN CUPLAJ CU SARCINĂ”

- În acest tip de analiză, partea mobilă antrenează o sarcină exterioară.
- Doar pe acest tip de analiză se practică cuplajul magneto-mecanic, adică sunt rezolvate și problemele de câmp electromagnetic și cele de mișcare. Analiza se realizează în modulul Transient Magnetic.
- Pentru rezolvare se folosește ca parametru intermediar timpul sau poziția.

4.4.2. Post-processing quantities: translation motion (2D)

Introduction This paragraph deals with physical quantities computed for translation motion with translating air gap in 2D.

Kinematic variables The list of kinematic variables used for solving are given in the table below.

Kinematic variable	Name	Unit
Linear position: y	Position	m
Linear speed: \dot{y}	Velocity	m/s
Linear acceleration: \ddot{y}	-	m/s ²

Computed physical quantities The list of physical quantities computed in the post-processing module are given in the table below.

Quantity	Name	Unit	Explanation
Electromagnetic force: F_{em}	Magnetic force	N	
Friction force: F_0 (relative to coefficient f_0)	Resistive force	N	$F_0 = f_0$
Friction force : F_1 (relative to coefficient f_1)	Friction force	N	$F_1 = f_1 \cdot \dot{y}$
Spring return force: F_k	Spring force	N	$F_k = k(y - y_0)$
Total resistant force: F_r	Force	N	$F_r = F_0 + F_1 + F_k$
	Force (pounds)	Pounds	
Mechanical power: P_m	Mechanical power	Watt	$P_m = F \cdot \dot{y}$

Reminder of the solved mechanical equation The solved mechanical equation for translation motion is:

$$m \ddot{y} = F_{em} - F_r$$

where:

- m is the mass
- F_{em} is the electromagnetic force
- F_r is the resistant force

Important note When there are symmetries and periodicities, the forces are computed for the part of the device represented.

4.4.3. Post-processing quantities: rotation motion (2D)

Introduction This paragraph deals with physical quantities computed for rotation motion with rotating air gap in 2D.

Kinematic variables The list of kinematic variables used for solving are given in the table below.

Kinematic variable	Name	Unit
Angular position: θ	Position	degree
Angular speed: $\dot{\theta}$	Velocity	degree/s
Angular acceleration: $\ddot{\theta}$	-	degree/s ²

Computed physical quantities The list of physical quantities computed in the post-processing module are given in the table below.

Quantity	Name	Unit	Explanation
Electromagnetic torque: Γ_{em}	Magnetic torque	N.m	
Friction torque: Γ_0 (relative to coefficient f_0)	Resistive torque	N.m	$\Gamma_0 = f_0$
Friction torque: Γ_1 (relative to coefficient f_1)	Friction torque	N.m	$\Gamma_1 = f_1 \cdot \dot{\theta}$
Spring return torque: Γ_k	Spring torque	N.m	$\Gamma_k = k(\theta - \theta_0)$
Total resistant torque: Γ_r	Torque	N.m	$\Gamma_r = \Gamma_0 + \Gamma_1 + \Gamma_k$
	Torque (foot-pounds)	Foot-pound s	
Mechanical power: P_m	Mechanical power	Watt	$P_m = \Gamma \cdot \dot{\theta}$

Reminder of the solved mechanical equation The solved mechanical equation for rotation motion is:

$$J \ddot{\theta} = \Gamma_{em} - \Gamma_r$$

where:

- J is the moment of inertia
- Γ_{em} is the electromagnetic torque
- Γ_r is the resistant torque

Important note When there are symmetries and periodicities, the torques are computed for the part of the device represented.

