Circuitos Magnéticos

Revisão de conceitos básicos

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Circuitos Magnéticos

- Composto por
  - Peças (móveis e/ou fixas)
  - Enrolamento/ímã permanente
- Tipos de materiais
  - Paramagnéticos (ex. Alumínio) μ_r um pouco maior do que 1
  - Diamagnéticos (ex. Cobre) μ_r um pouco menor do que 1
  - Ferromagnéticos μ_r muito maior do que 1
- **Campos magnéticos produzidos por circuitos magnéticos**

$$FMM_T = \Re_T \varphi$$

Fluxo pode ser calculado por

$$\varphi = \int_A \vec{B} \bullet d\vec{A}$$

Lei de Ampère

$$\oint \vec{H} \bullet d\vec{l} = I$$

$$\Re = \frac{\oint \vec{H} \bullet d\vec{l}}{\int_A \vec{B} \bullet d\vec{A}}$$

Circuito elétrico

$$V = R_T I$$

V – fem total no circuito

R_T – resistência total

I – corrente

Circuito magnético

$$FMM_T = \Re_T \varphi$$

FMM_T – fmm total no circuito

$\Re_T$ – relutância total

φ – fluxo através do circuito

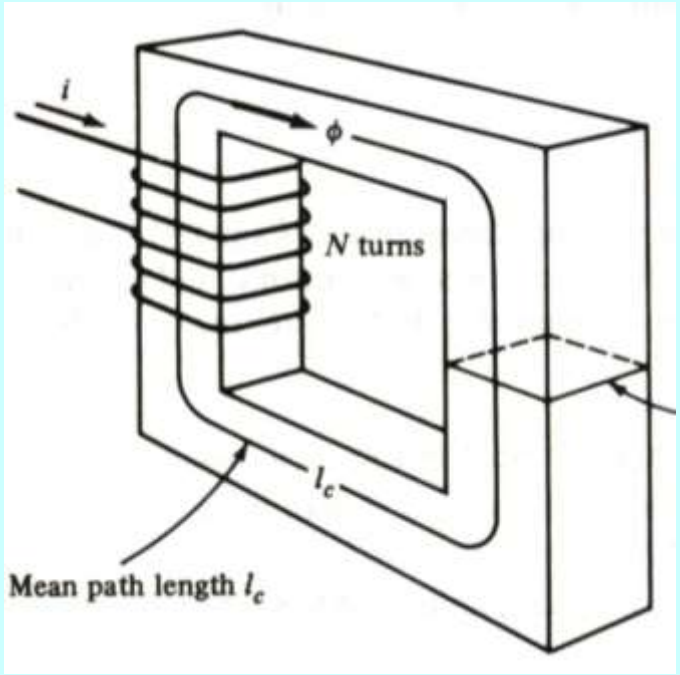
Circuitos Magnéticos

- Lei de Ampère $\oint \vec{H} \bullet d\vec{l} = I$
- I - Corrente enlaçada
- $\vec{H}$ - intensidade de campo magnético (ampère-espira/metro)
- $\vec{l}$ - caminho de integração

$$H l_c = N i$$ (Força Magnetomotriz)

$$H = \frac{Ni}{l_C}$$

l_c – caminho médio



Circuitos Magnéticos

- $\vec{B} = \mu \vec{H}$

- B - densidade de fluxo magnético (Wb/m^2, tesla, T)

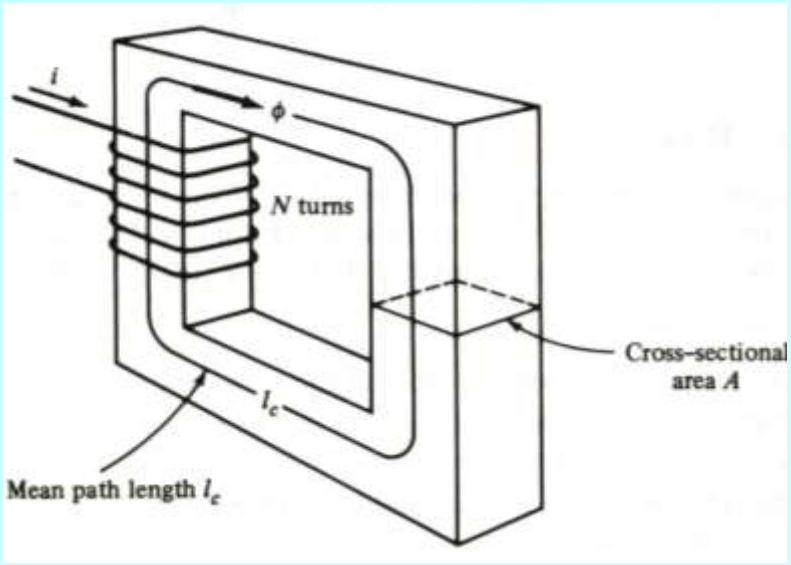
  μ - permeabilidade magnética do material (H/m)

  $\mu_0 = 4 \pi \times 10^{-7}$ H/m

  $$\mu_r = \frac{\mu}{\mu_0}$$ permeabilidade relativa

Circuitos Magnéticos

$$H = \frac{Ni}{l_c} \quad , \quad B = \mu H = \frac{\mu N i}{l_c}$$



$$\varphi = \int_A \vec{B} \bullet d\vec{A}$$

- **Considerando** B constante e perpendicular a A

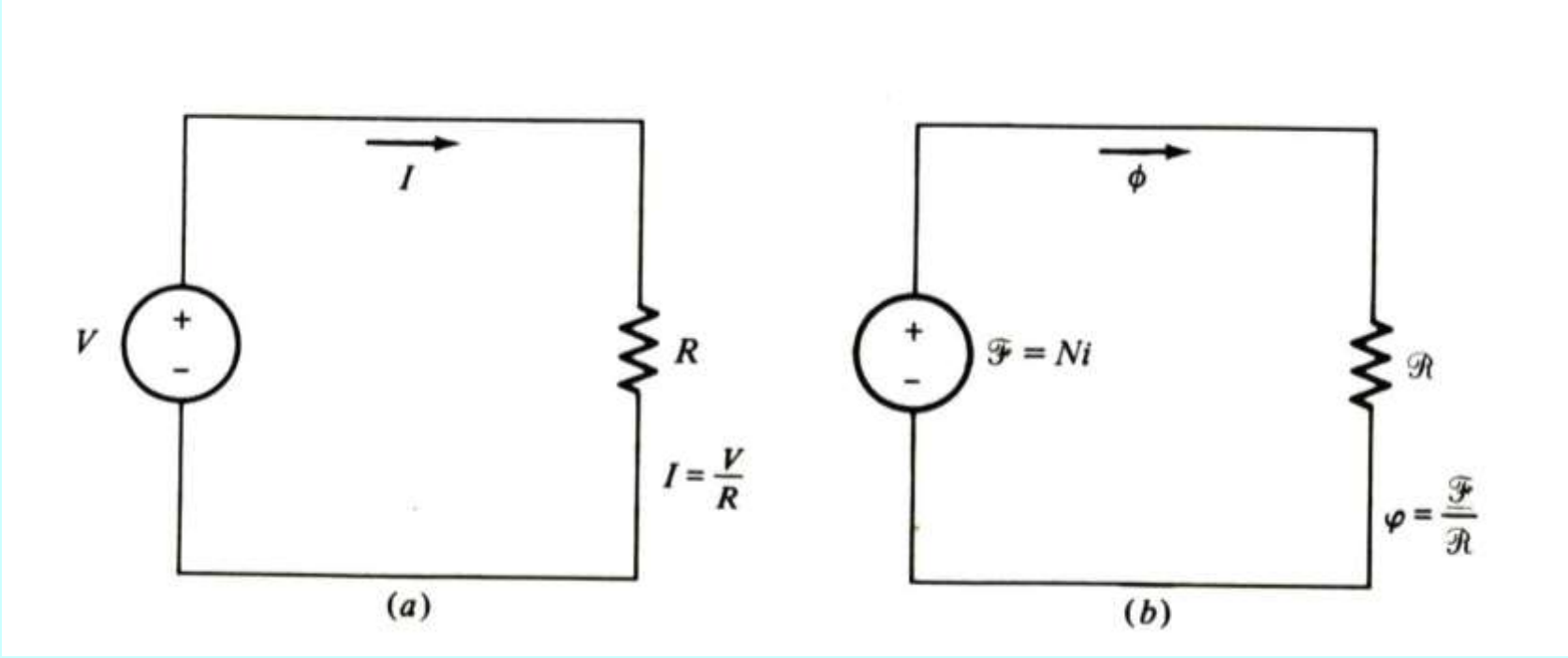
$$\varphi = B\,A = \frac{\mu N i A}{l_c}$$

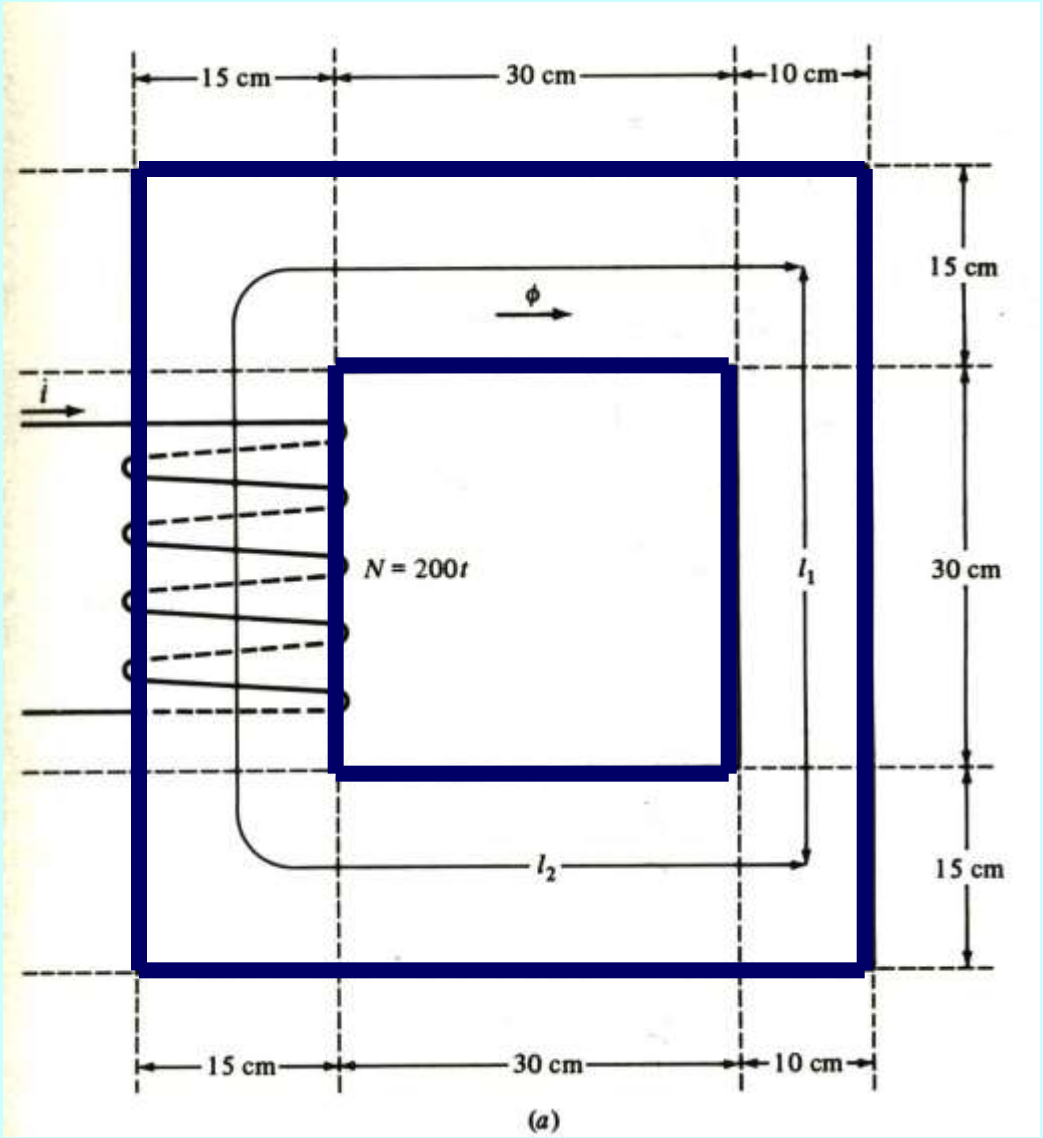
$$FMM = Ni = \varphi \frac{l_c}{\mu A} = \Re_c \varphi$$

$$\Re_c = \frac{l_c}{\mu A}$$

Relutância

$$FMM = N\,i = \Re_c \varphi$$





μ_r= 2500 (todo o fluxo contido no núcleo ferromagnético)

I=1A profundidade=10cm **B=?**

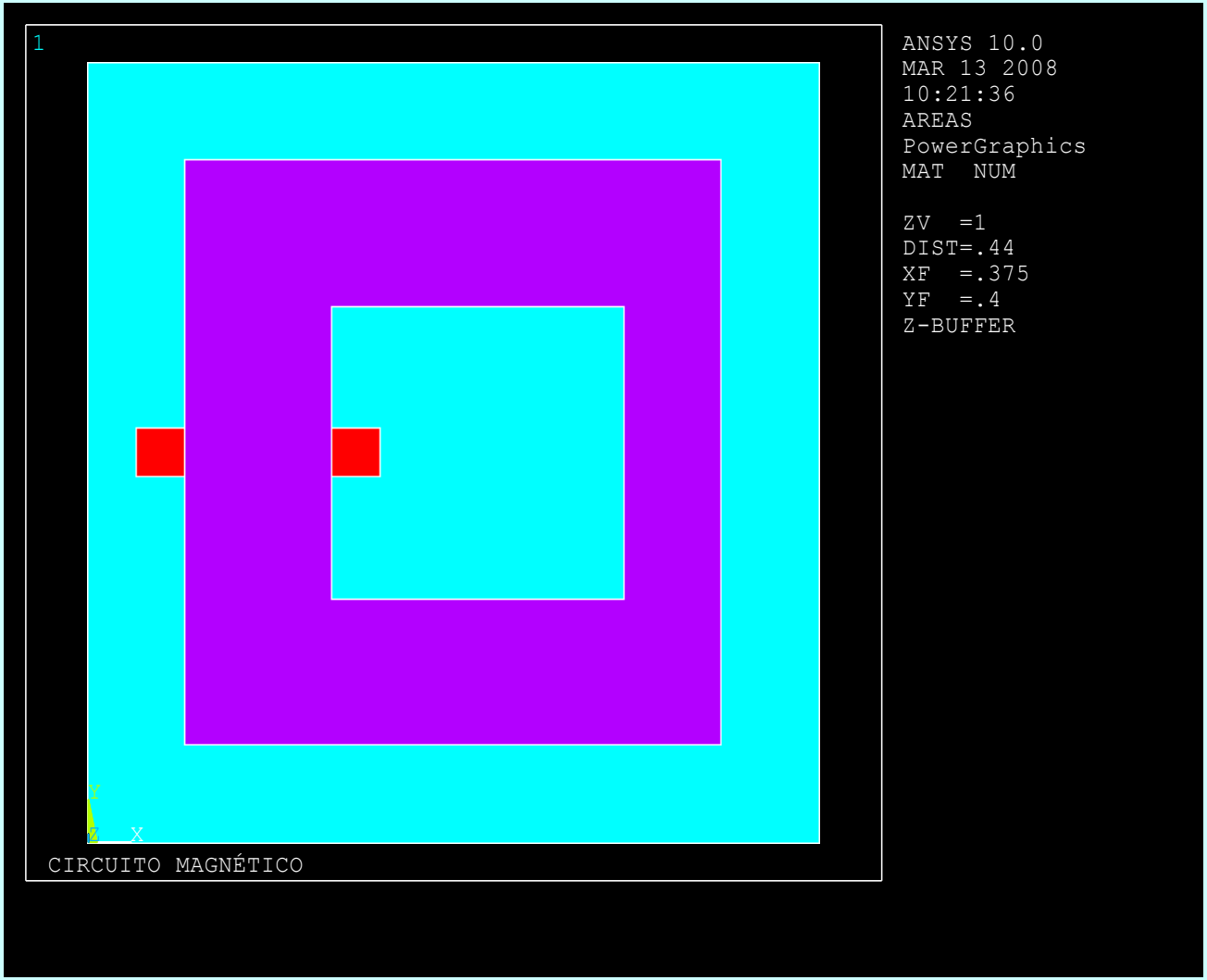
μ_r= 2500 (todo o fluxo contido no núcleo ferromagnético)

$$\Re_1 = \frac{l_1}{\mu_r \mu_0 A} = 14300 \text{A.espiras/Wb} \qquad \Re_2 = \frac{l_2}{\mu_r \mu_0 A} = 27600 \text{A.espiras/Wb}$$

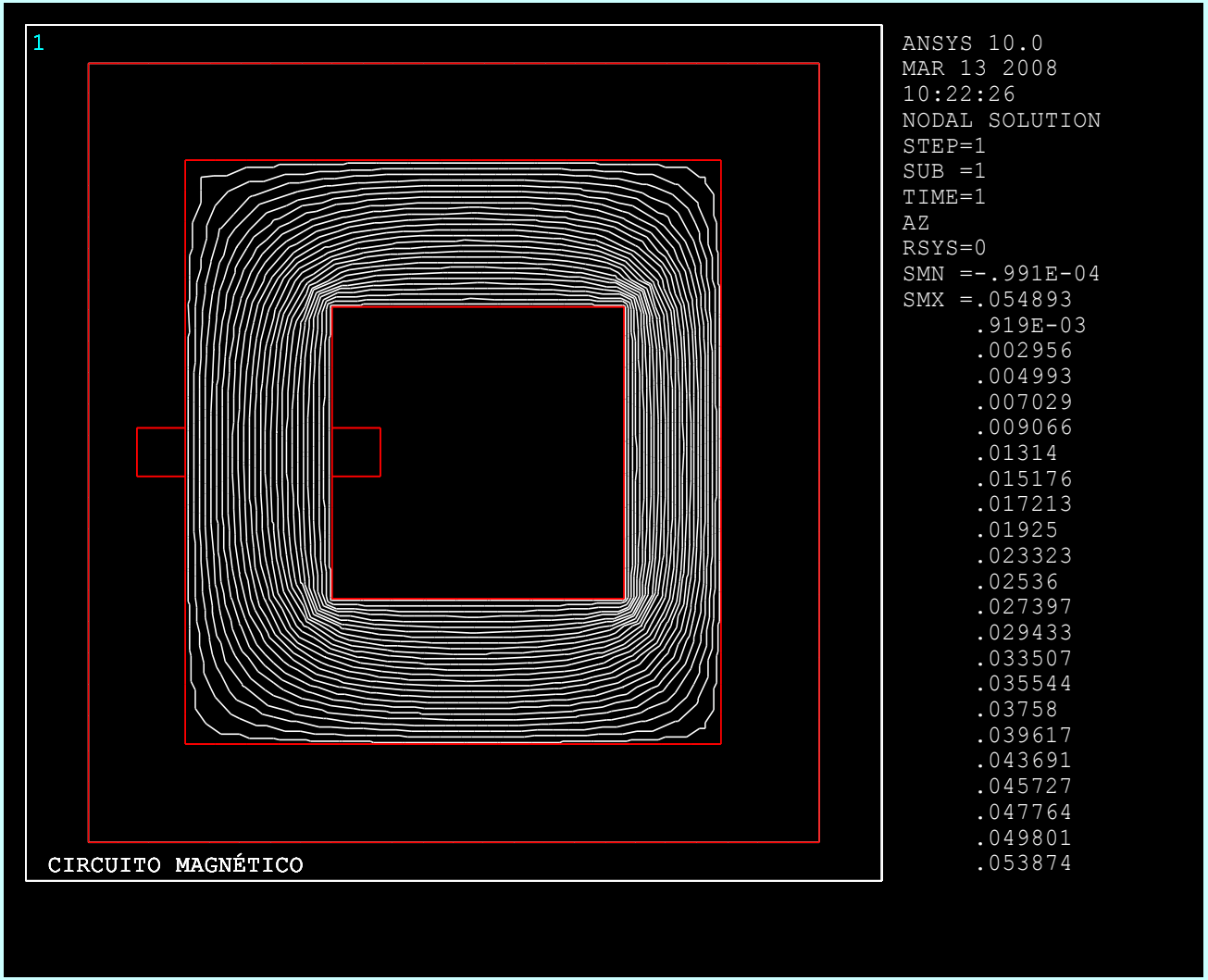
$$N\,i = (\Re_1 + \Re_2)\varphi \longrightarrow \varphi = 0{,}0048 \text{ Wb}$$

$$B_1 = \frac{\varphi}{A_1} = 0{,}48\,\text{T} \qquad B_2 = \frac{\varphi}{A_2} = 0{,}32\,\text{T}$$

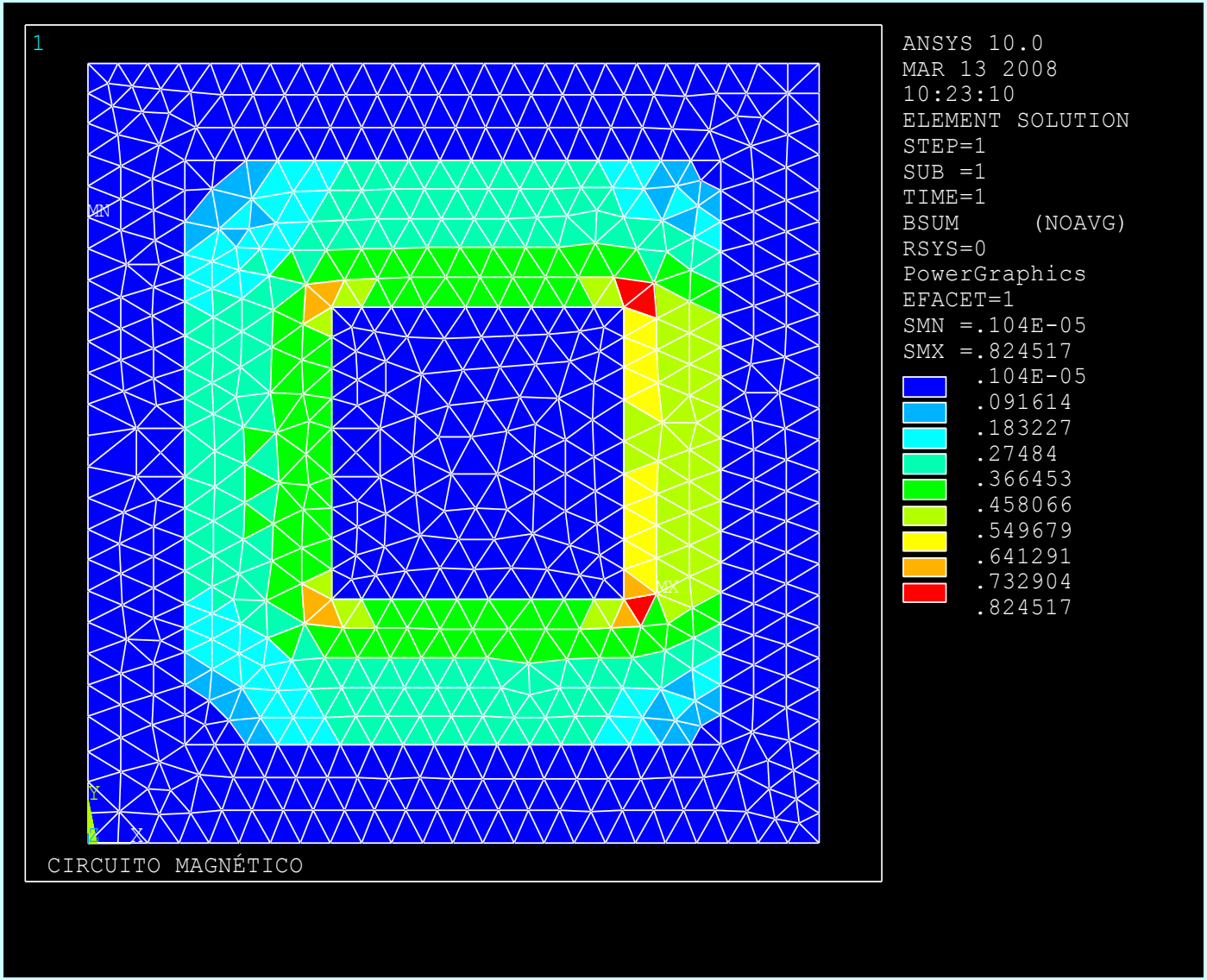
Resolução por elementos finitos



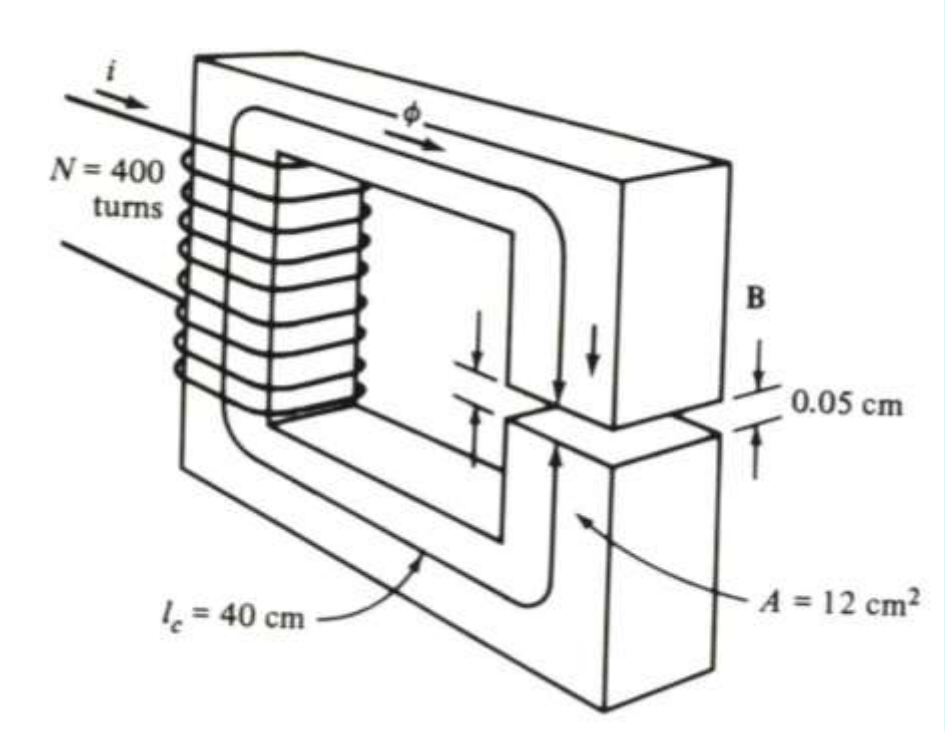
Resolução por elementos finitos



Resolução por elementos finitos



Circuitos Magnéticos

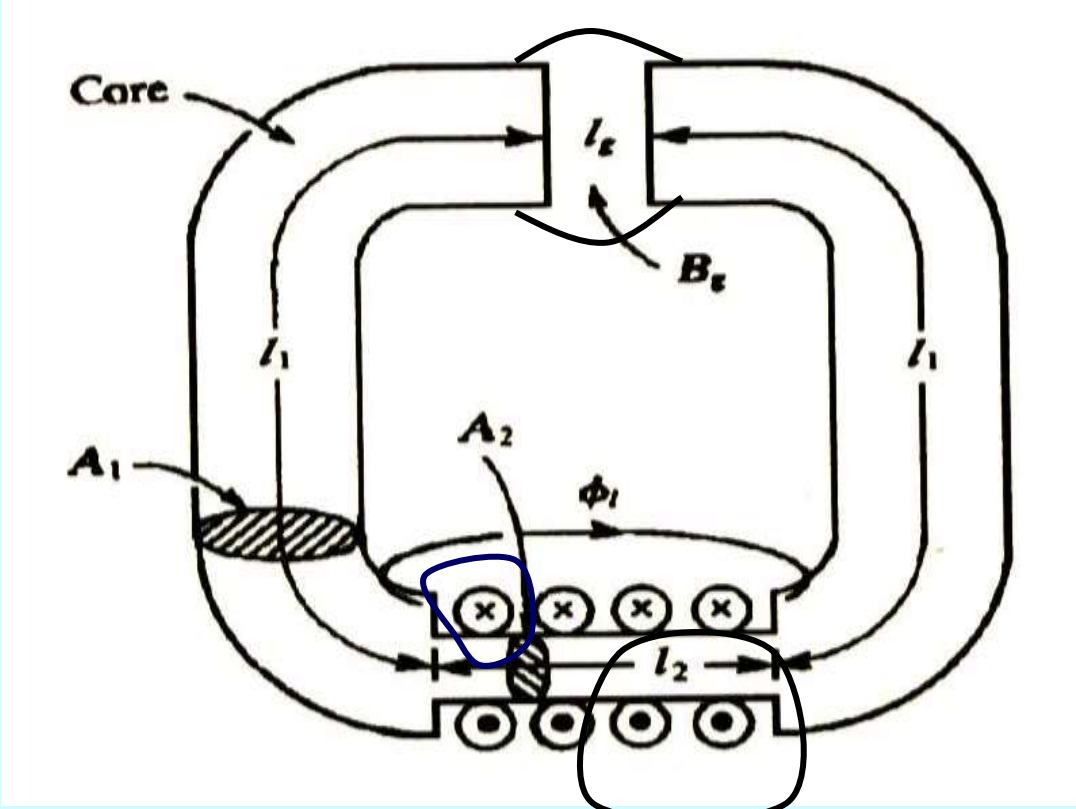


μ_r= 4000 (todo o fluxo contido no núcleo ferromagnético)

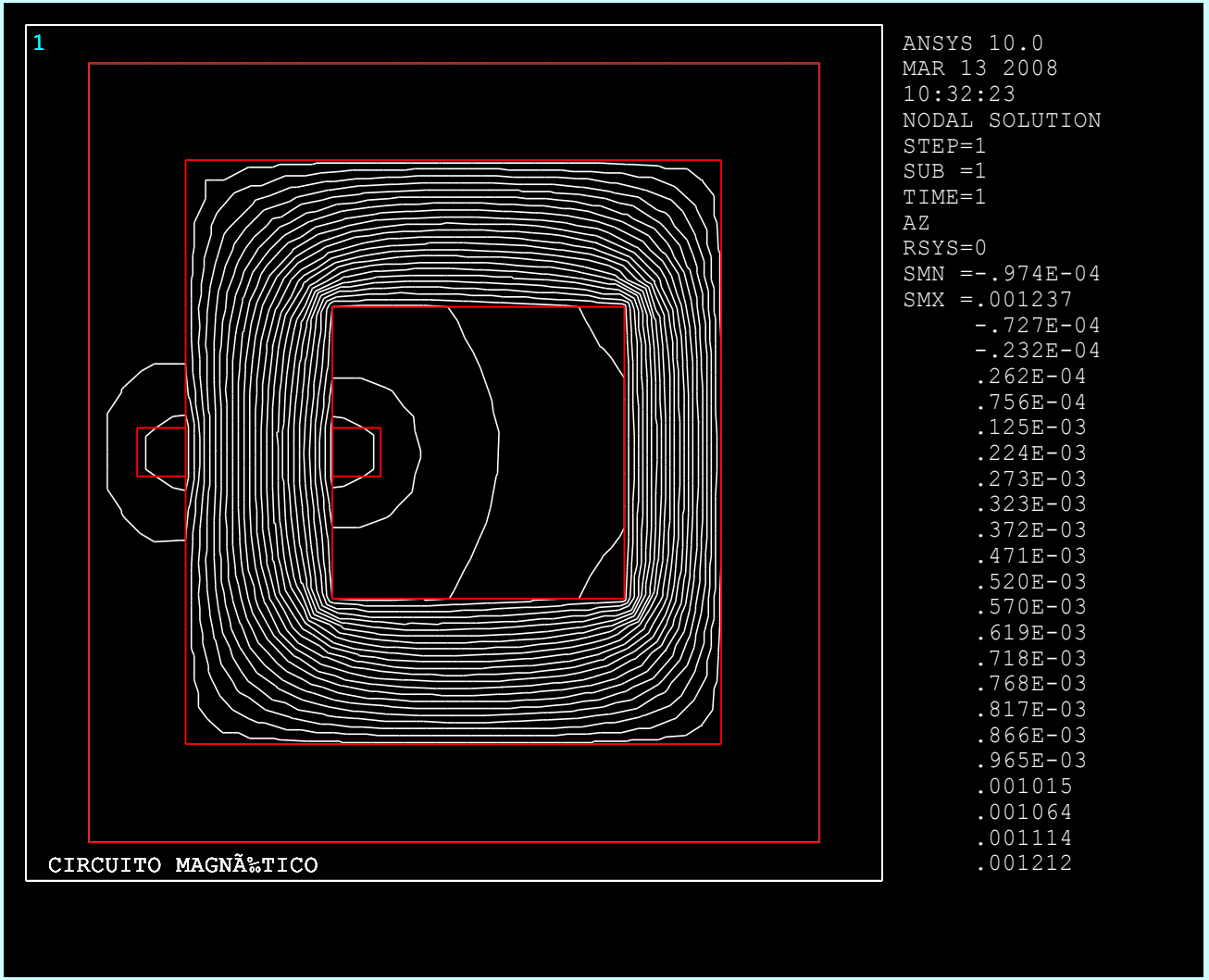
- Espraiamento aumenta a área efetiva do entreferro em 5%
- Quero B no entreferro de 0,5 T.
- **Calcule a corrente necessária**.

- Dispersão
- Saturação

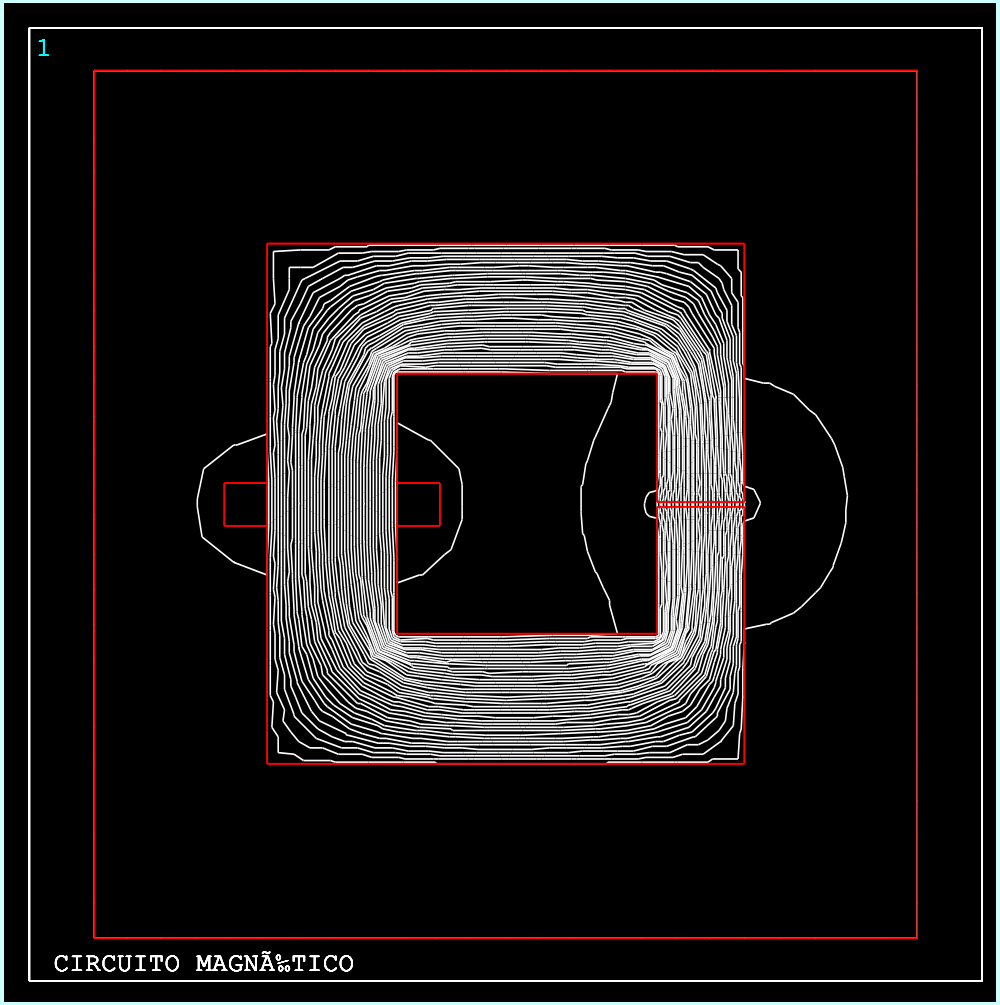
Dispersão



Dispersão


1
CIRCUITO MAGNÃ‰TICO
ANSYS 10.0
MAR 13 2008
10:32:23
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
AZ
RSYS=0
SMN =-.974E-04
SMX =.001237
-.727E-04
-.232E-04
.262E-04
.756E-04
.125E-03
.224E-03
.273E-03
.323E-03
.372E-03
.471E-03
.520E-03
.570E-03
.619E-03
.718E-03
.768E-03
.817E-03
.866E-03
.965E-03
.001015
.001064
.001114
.001212

Circuito com entreferro



Dispersão

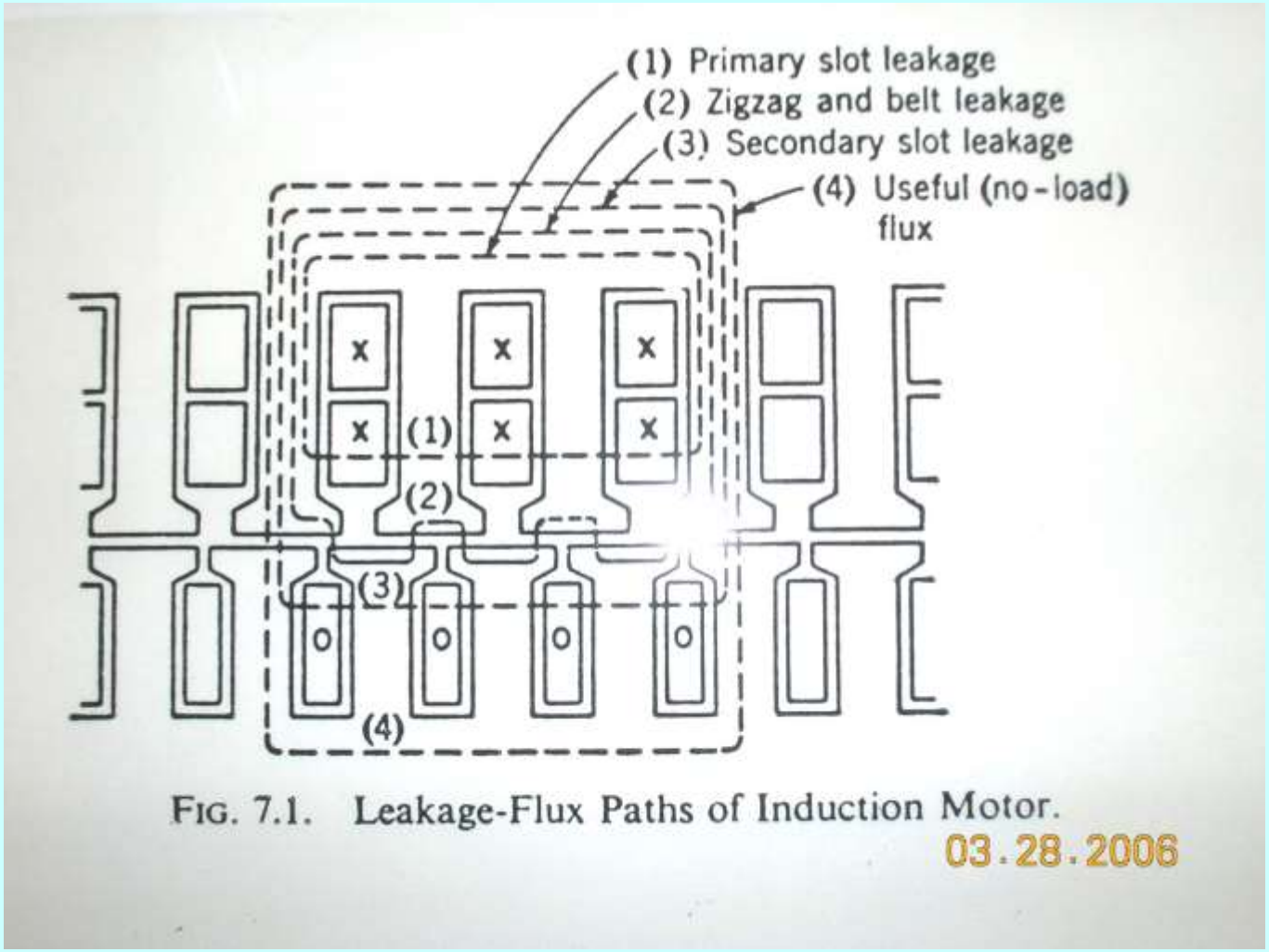
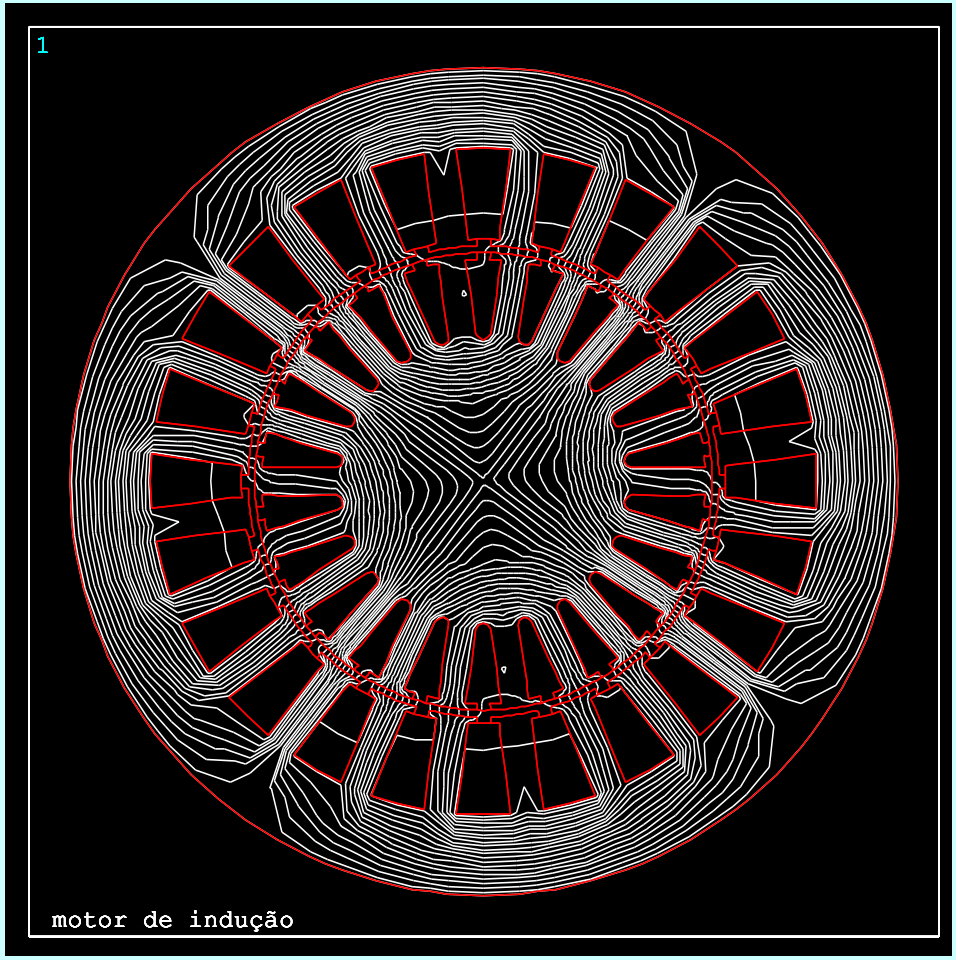
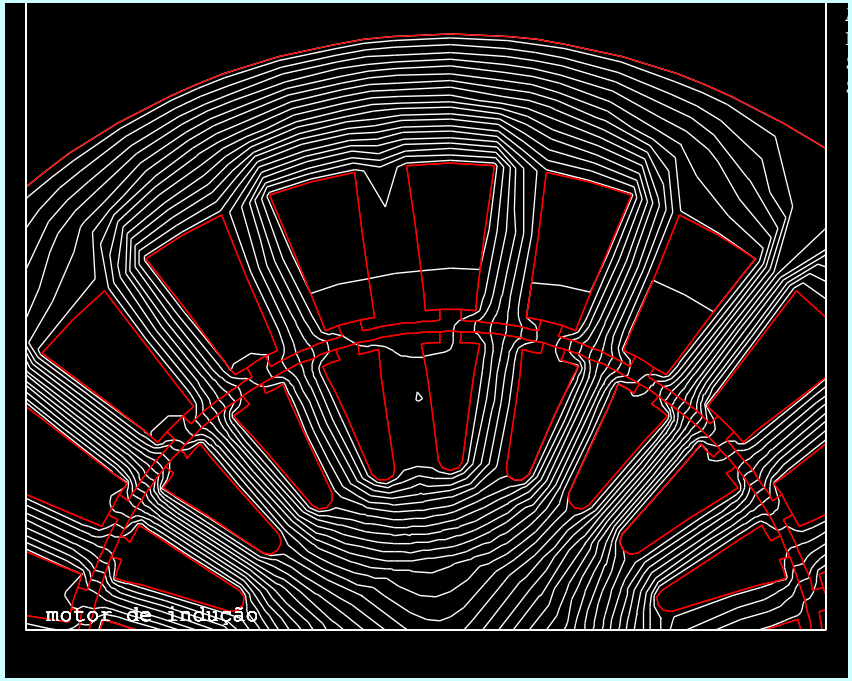


FIG. 7.1. Leakage-Flux Paths of Induction Motor.

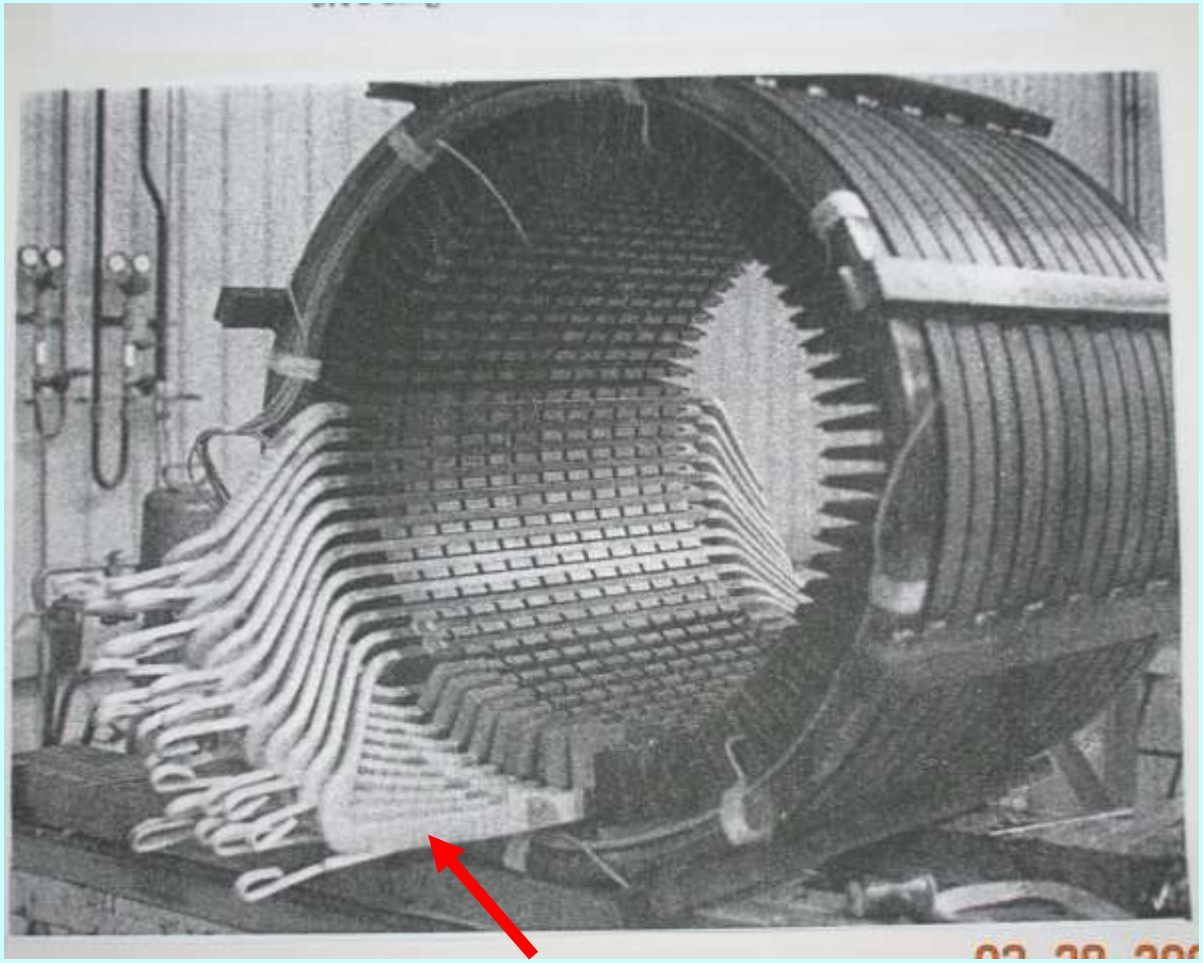
03.28.2006

Dispersão



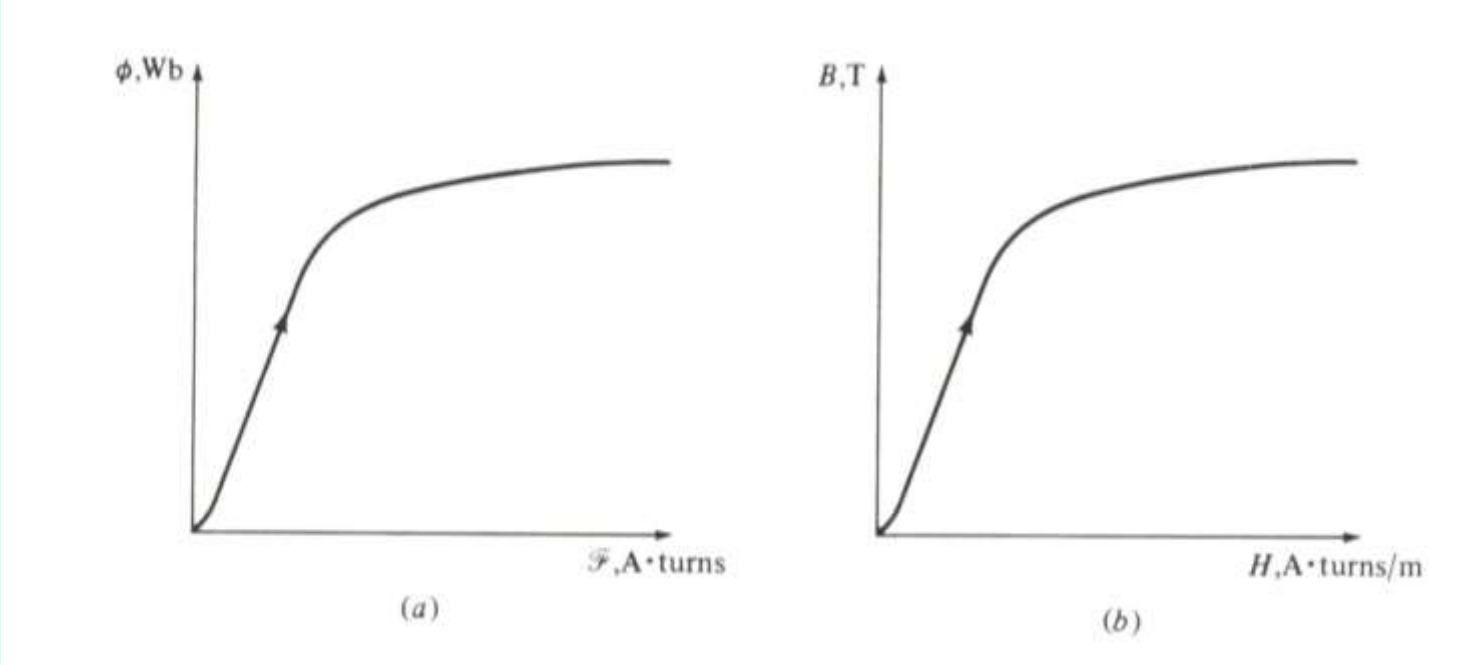


Dispersão



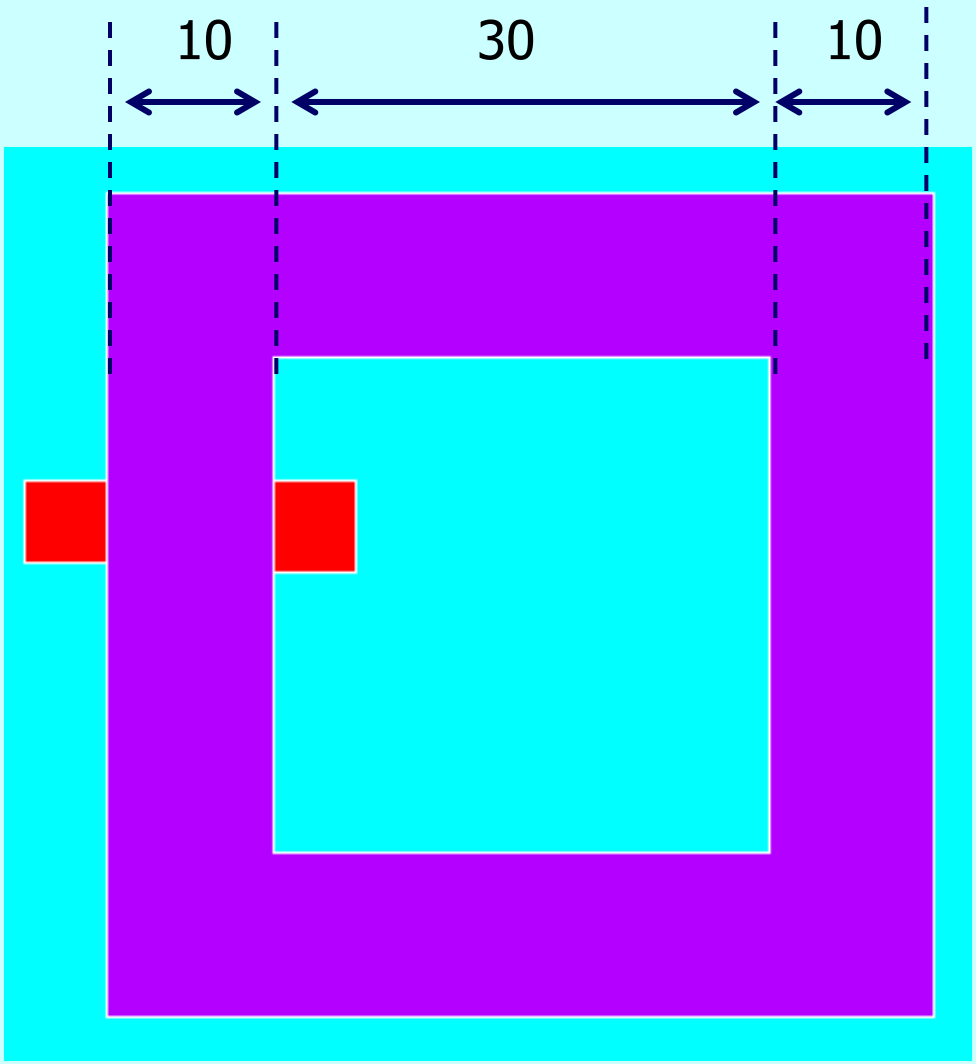
Cabeça de bobina

Saturação

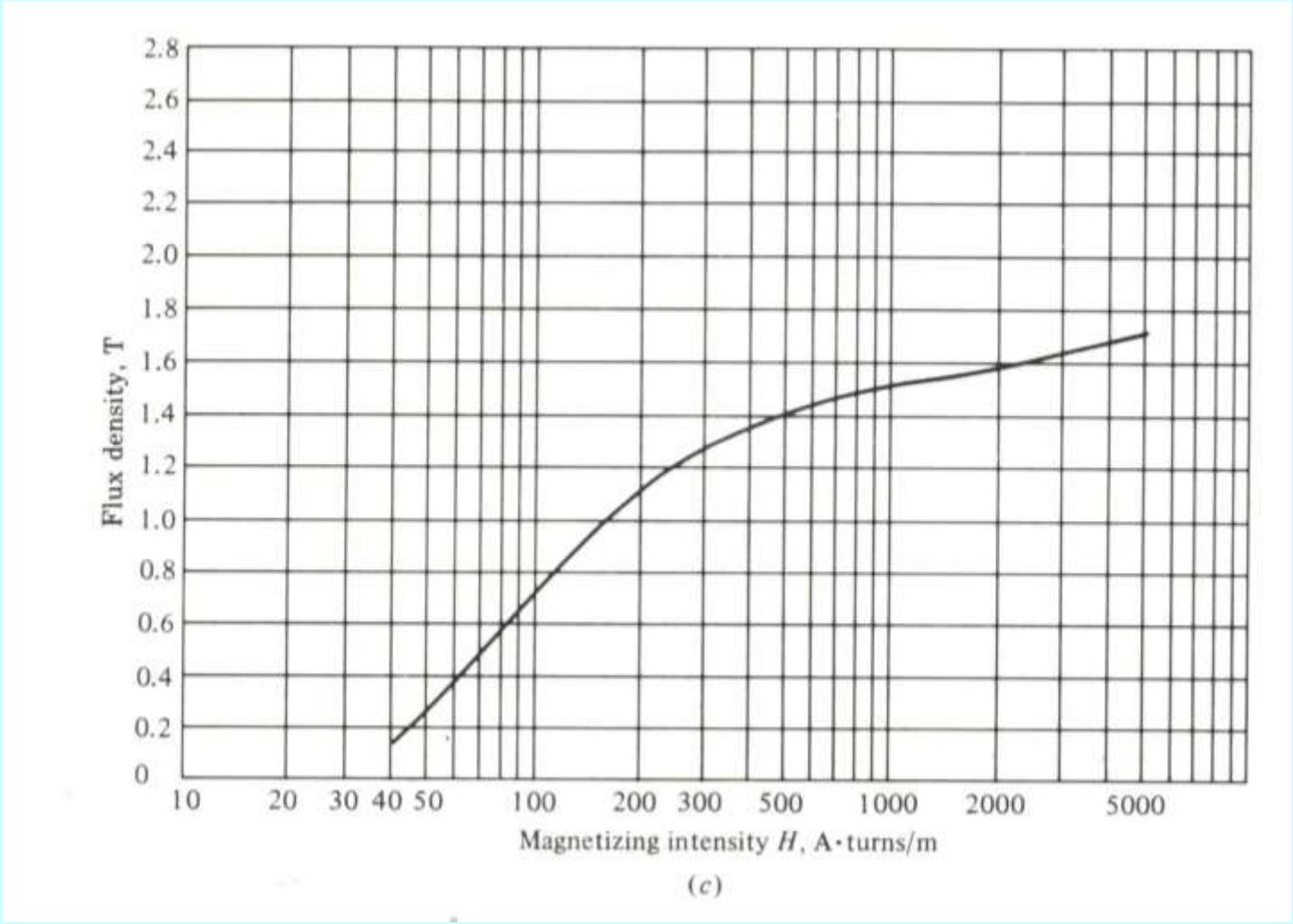


$$B = \mu H$$

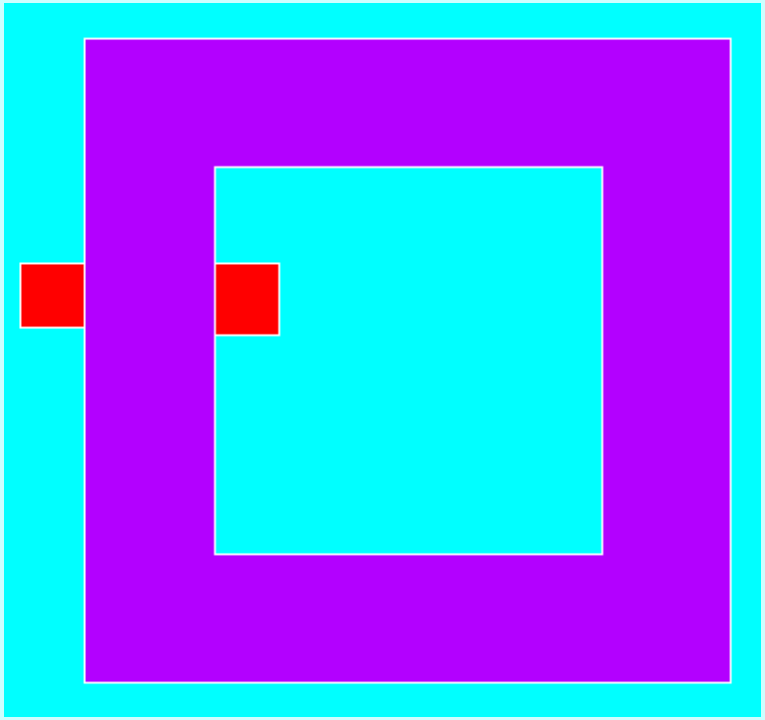
- Unidade [cm]
- profundidade =15
- N=200 espiras
- L_c = ?
- A = ?
- Φ=0,012 Wb
- I = ?

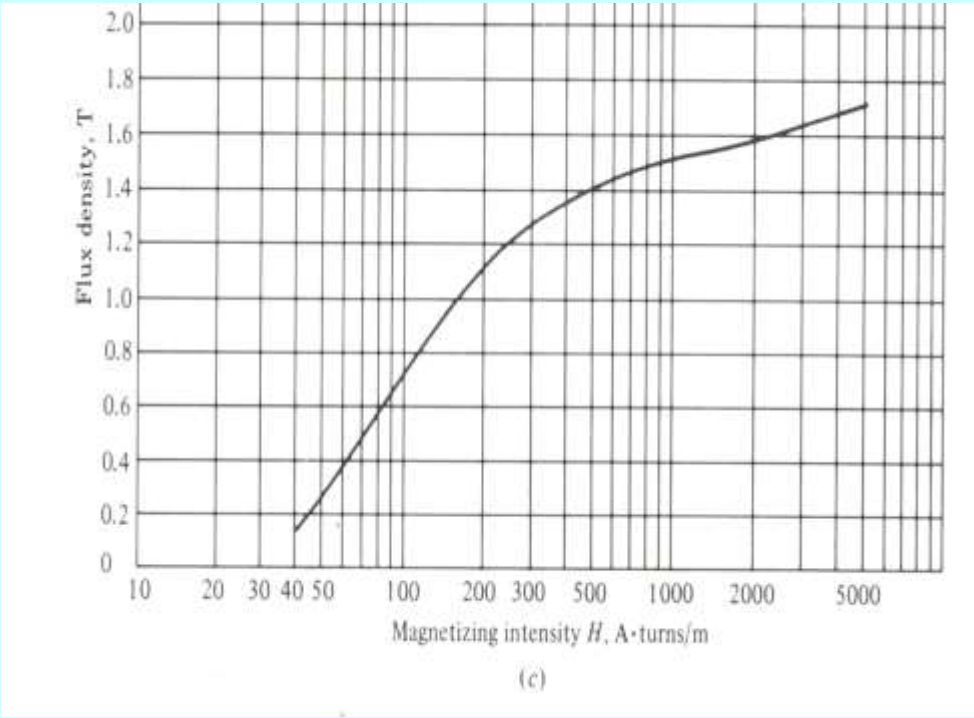


Saturação


Flux density, T
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
100
200
300
500
1000
2000
5000
Magnetizing intensity H, A·turns/m
(c)

Saturação

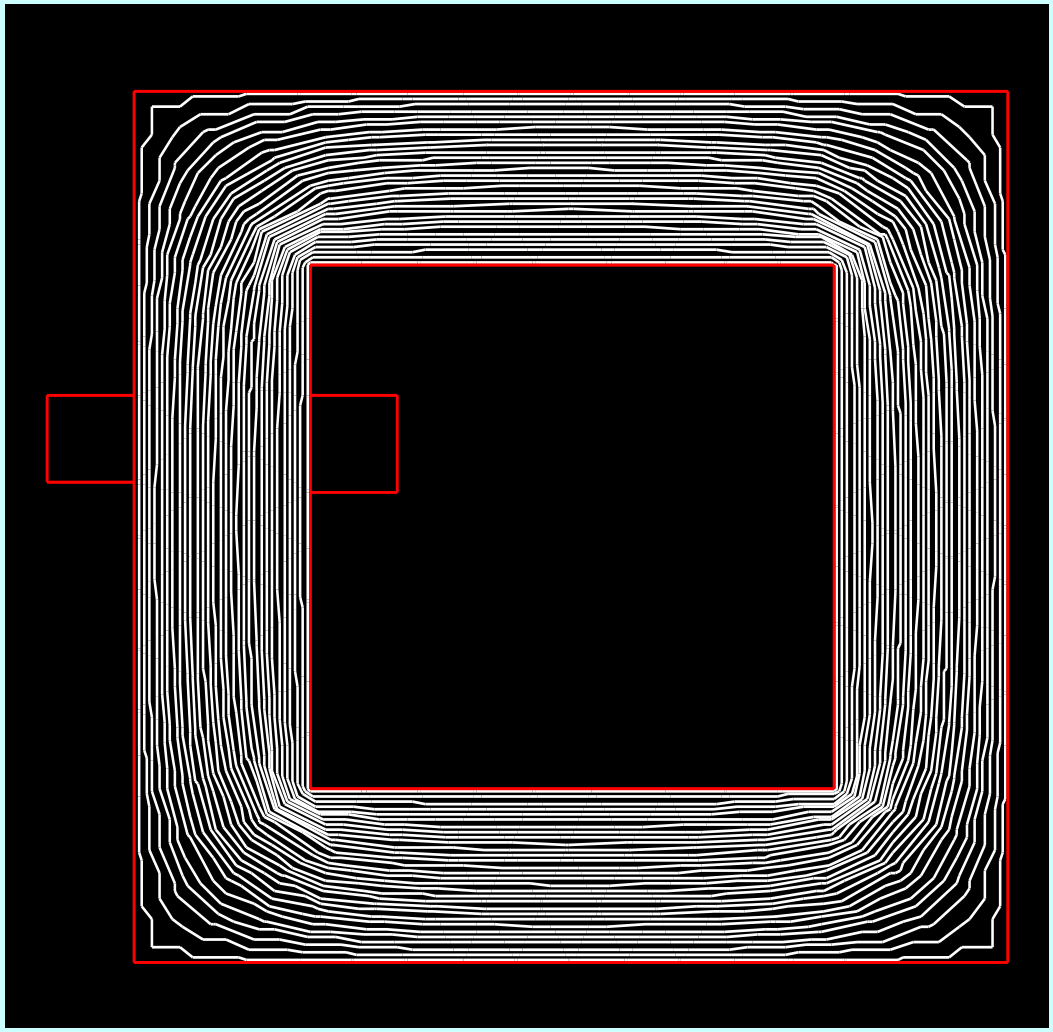




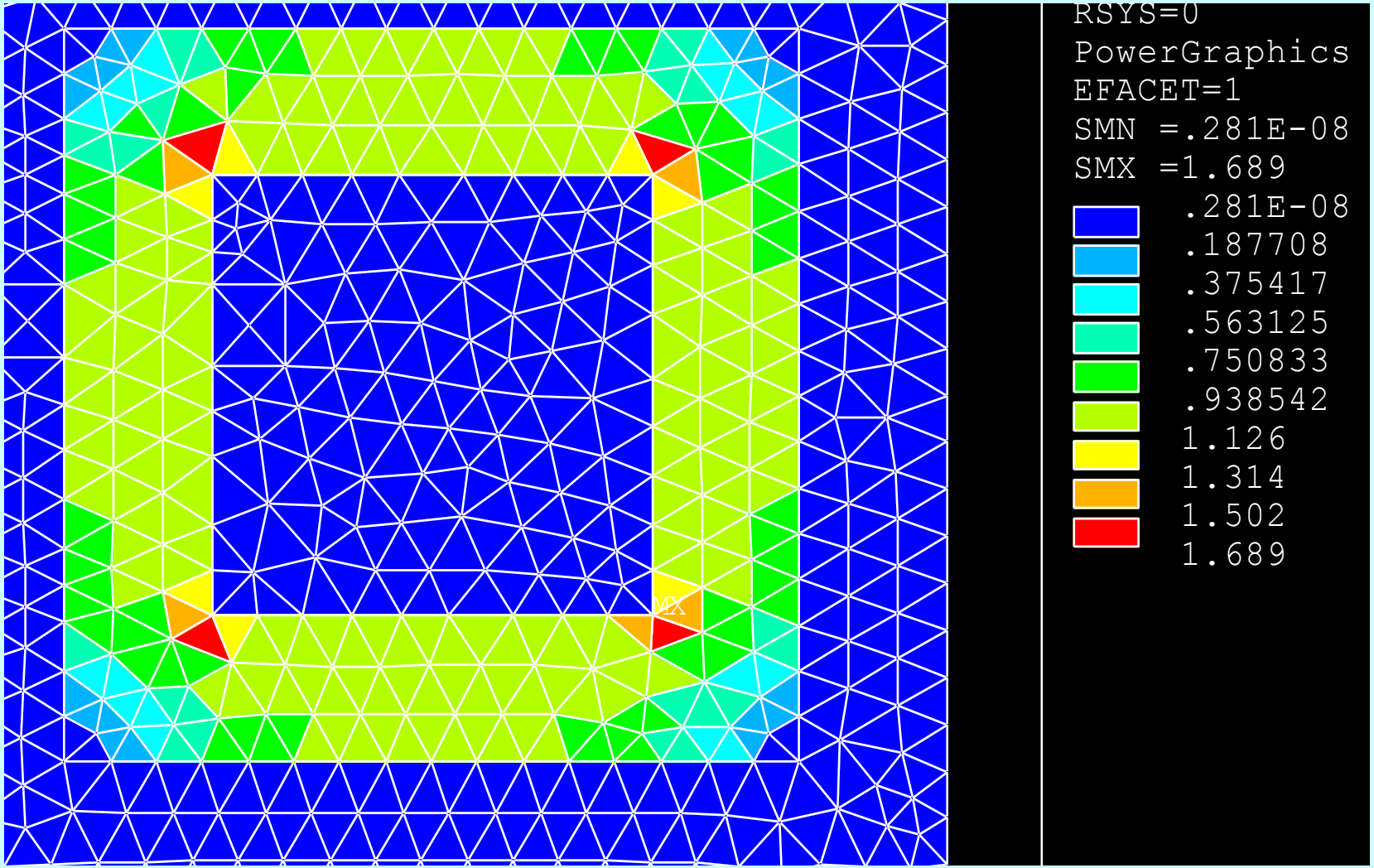
l_c=160cm A=150 cm² N=200 Φ=0,012 Wb

i=?

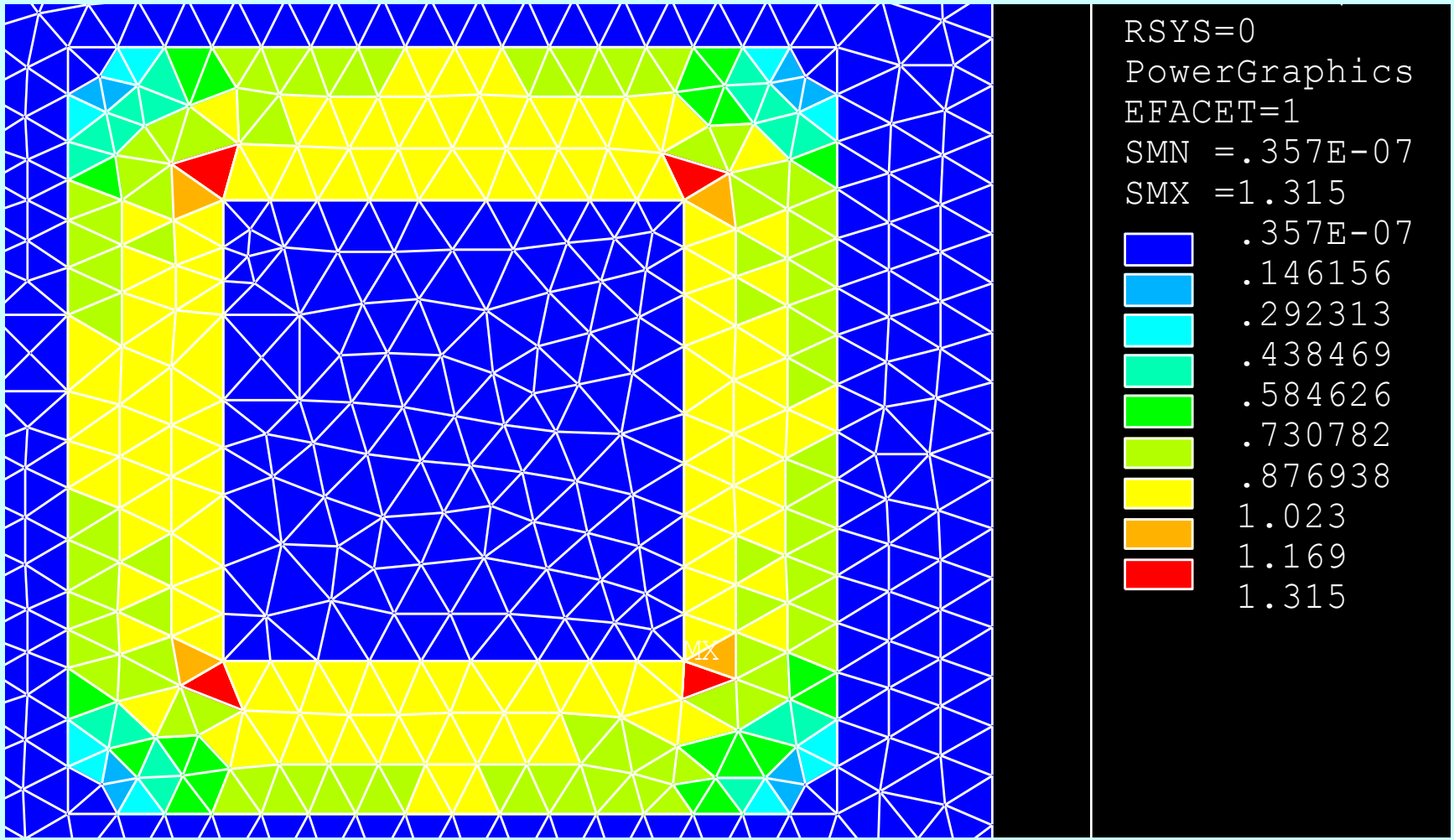
Saturação (Solução por MEF)



Saturação (permeabilidade do ferro fixa)



Saturação (curva de saturação)

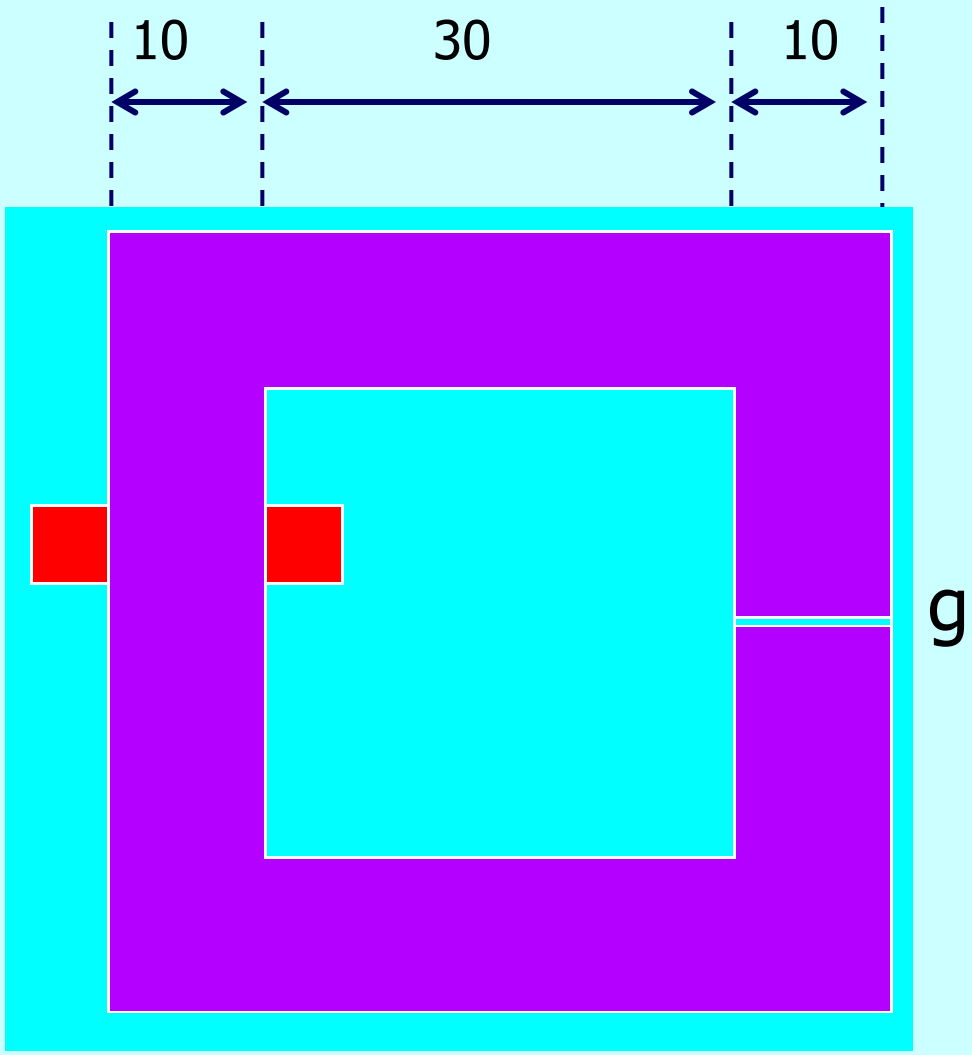


- Até agora, conhecíamos o campo e calculávamos a corrente para produzí-lo.

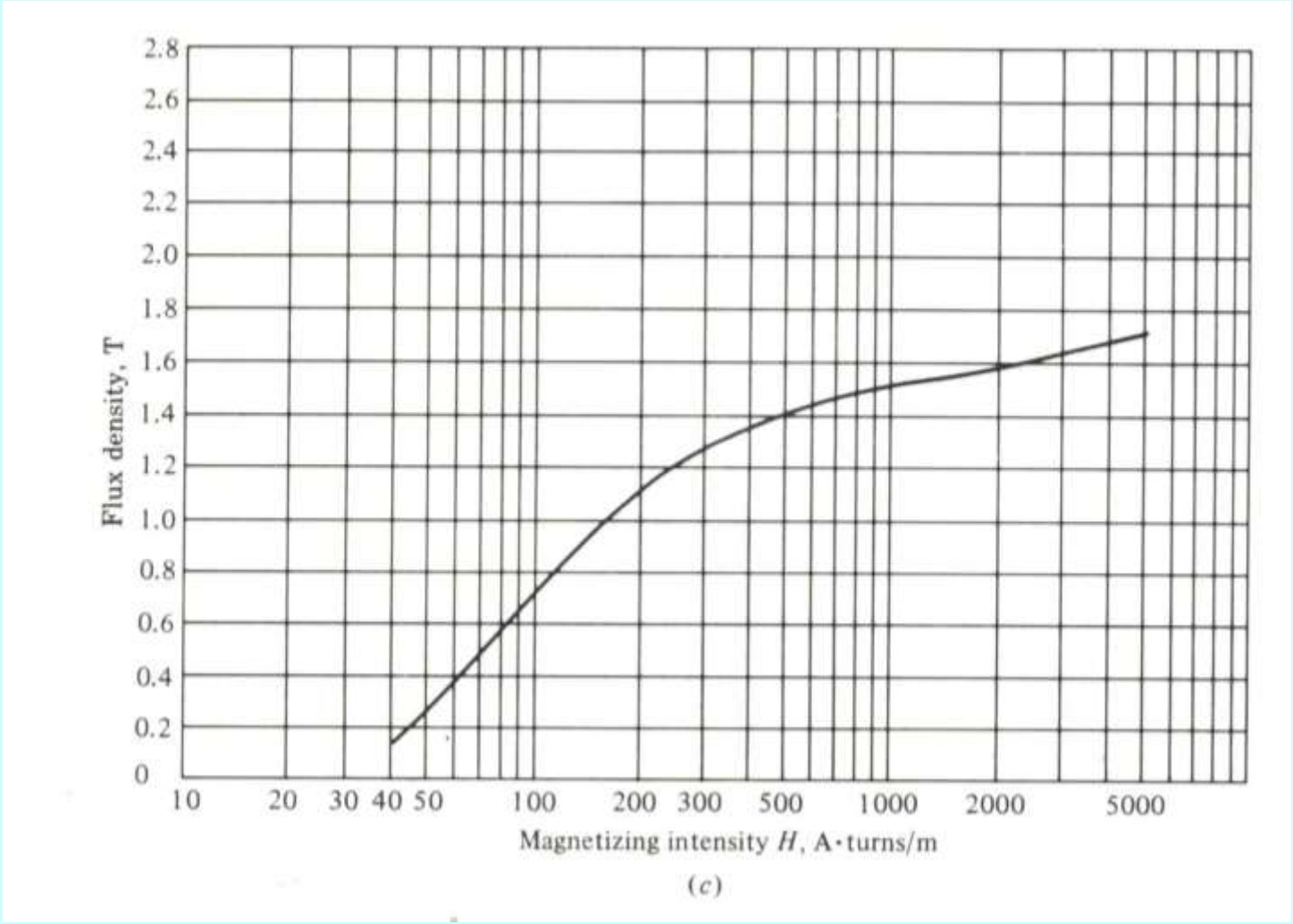
- Como fazer para calcular o fluxo conhecendo-se a corrente ?

Circuito com entreferro

- Unidade [cm]
- profundidade =15
- N=200 espiras
- g = 0,5
- L_c = 159,5
- A = 150 cm^2
- I = 20 A
- **B no entreferro = ?**

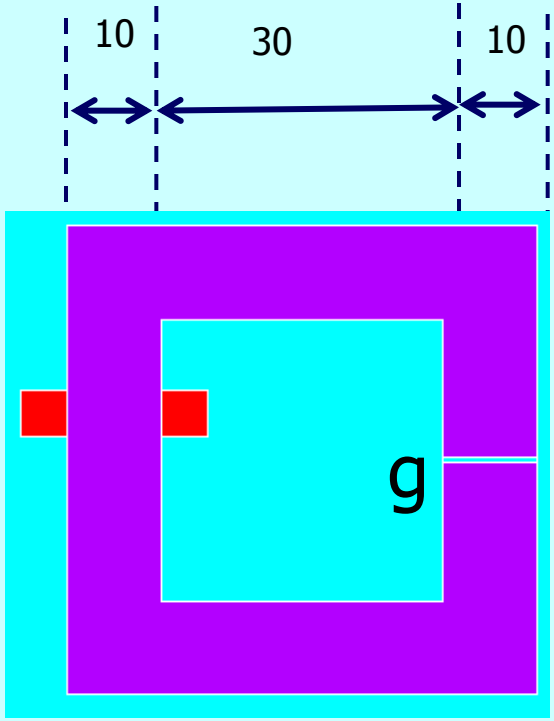


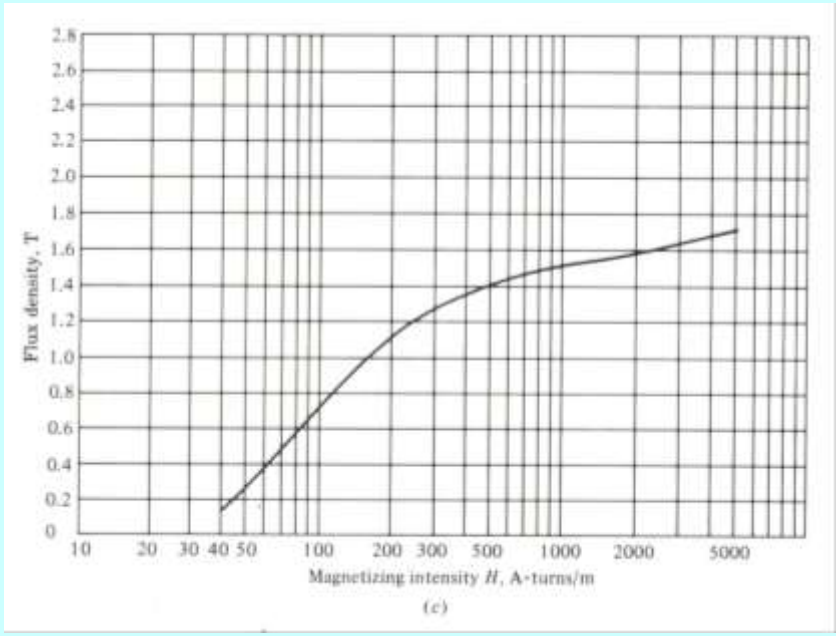
Saturação


Flux density, T
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
100
200
300
500
1000
2000
5000
Magnetizing intensity H, A·turns/m
(c)

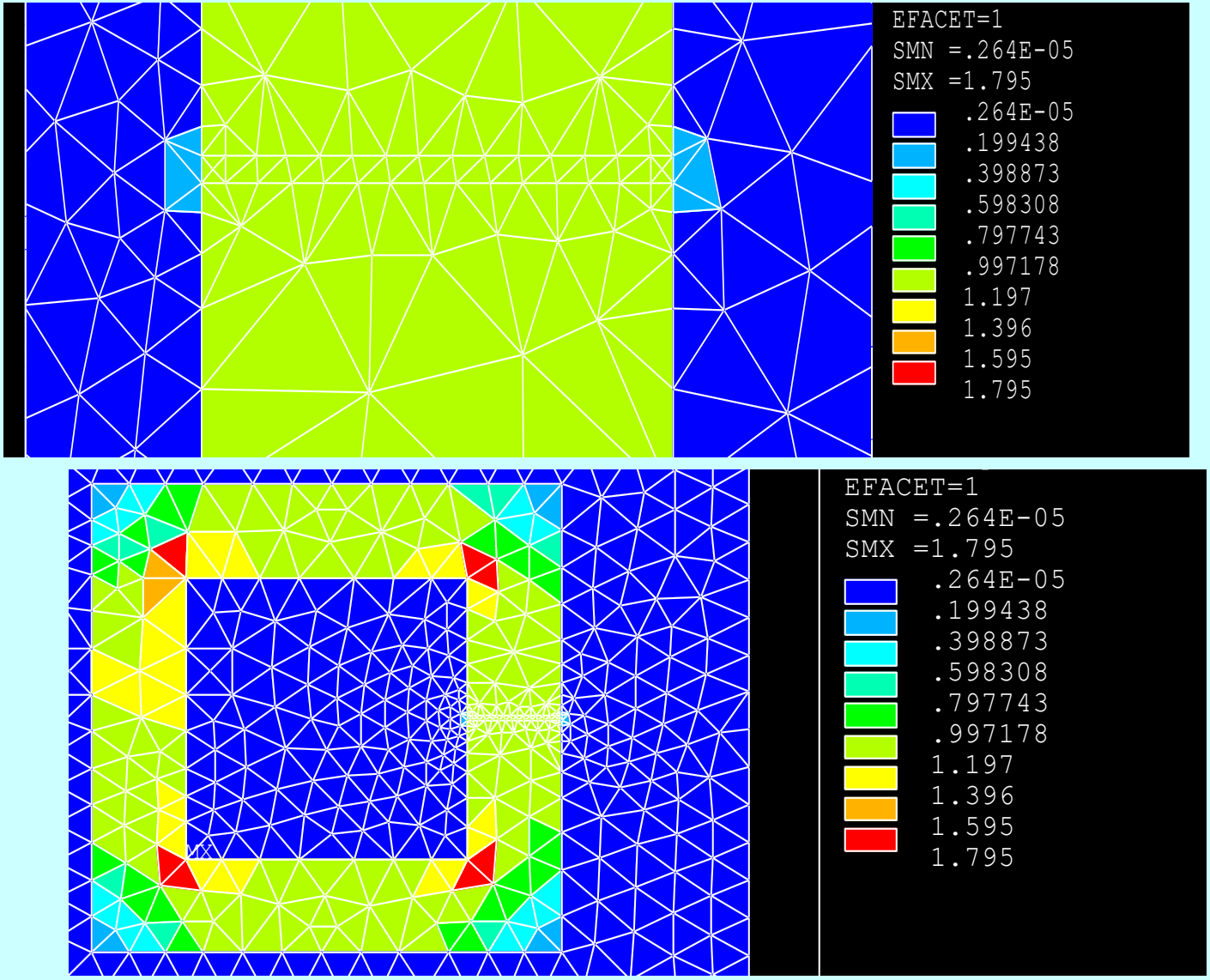
Circuito com entreferro

- Unidade [cm]
- profundidade =15
- N=200 espiras
- g = 0,5
- L_c = 159,5
- A = 150 cm^2
- I = 20 A
- **B no entreferro = ?**

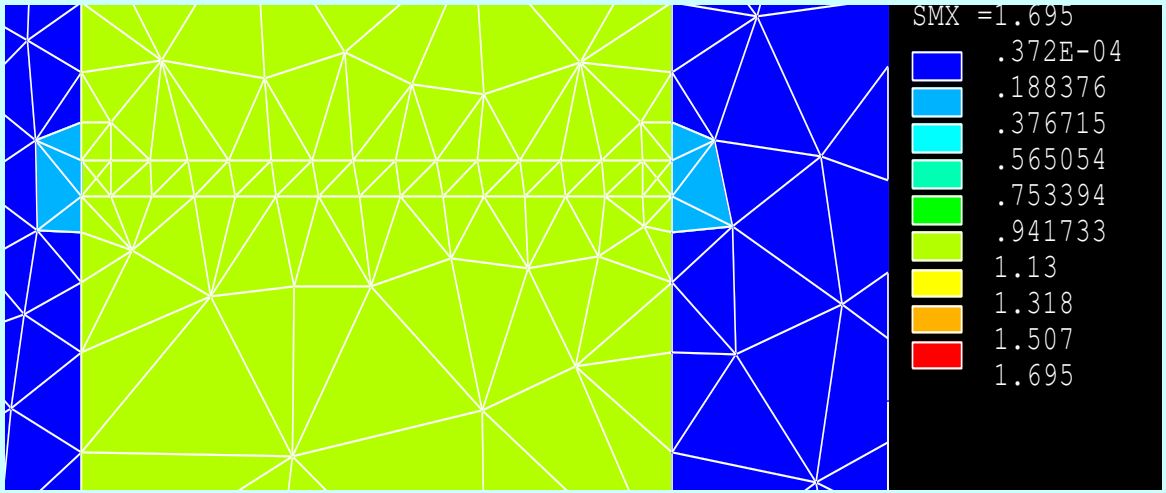


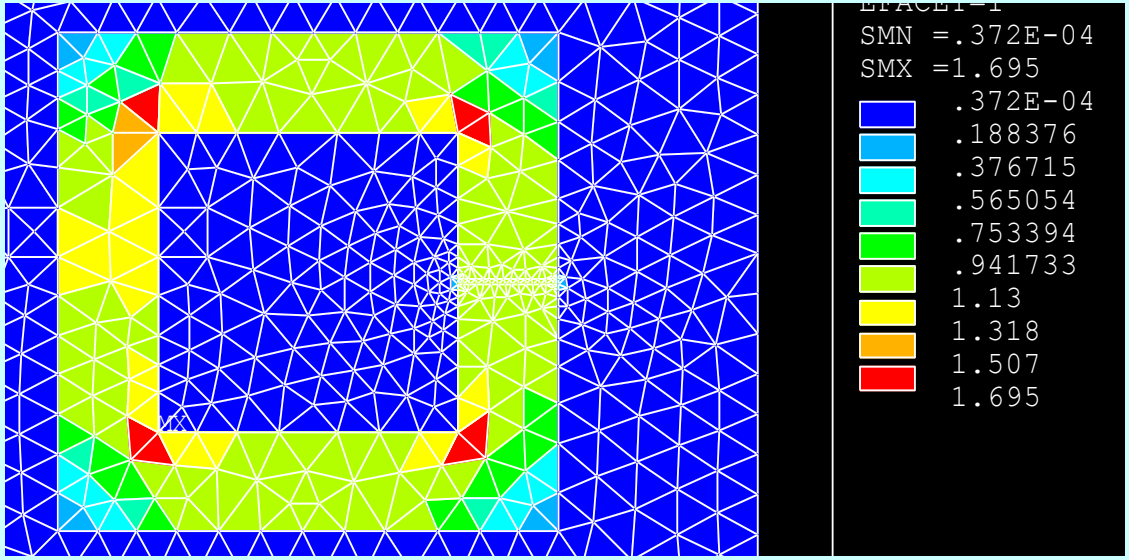


Permeabilidade ferro infinita

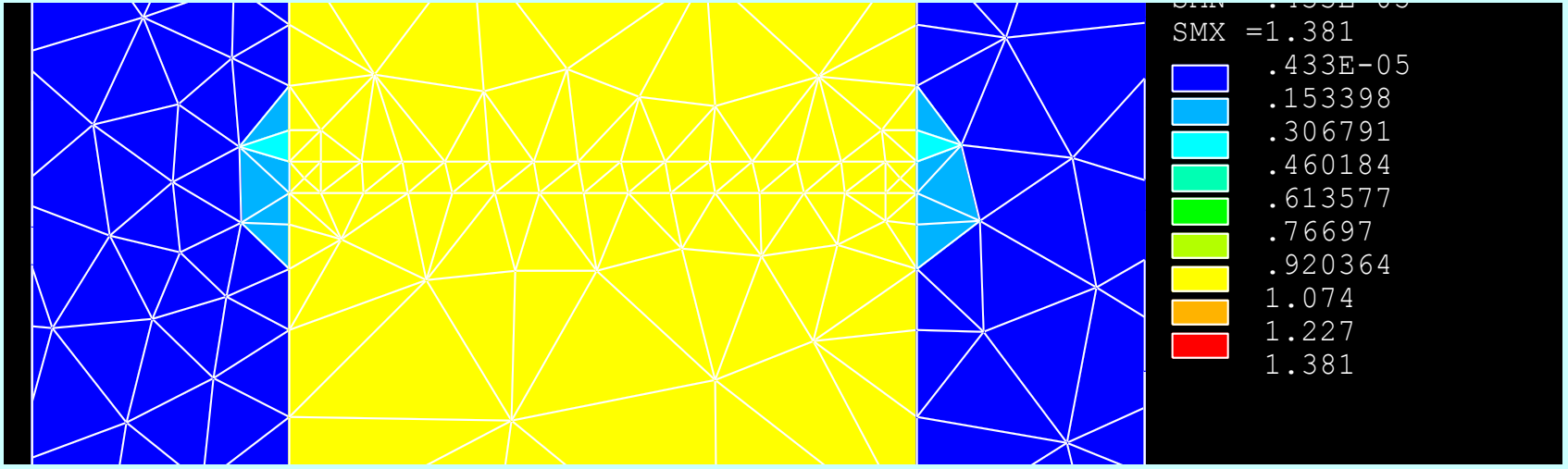


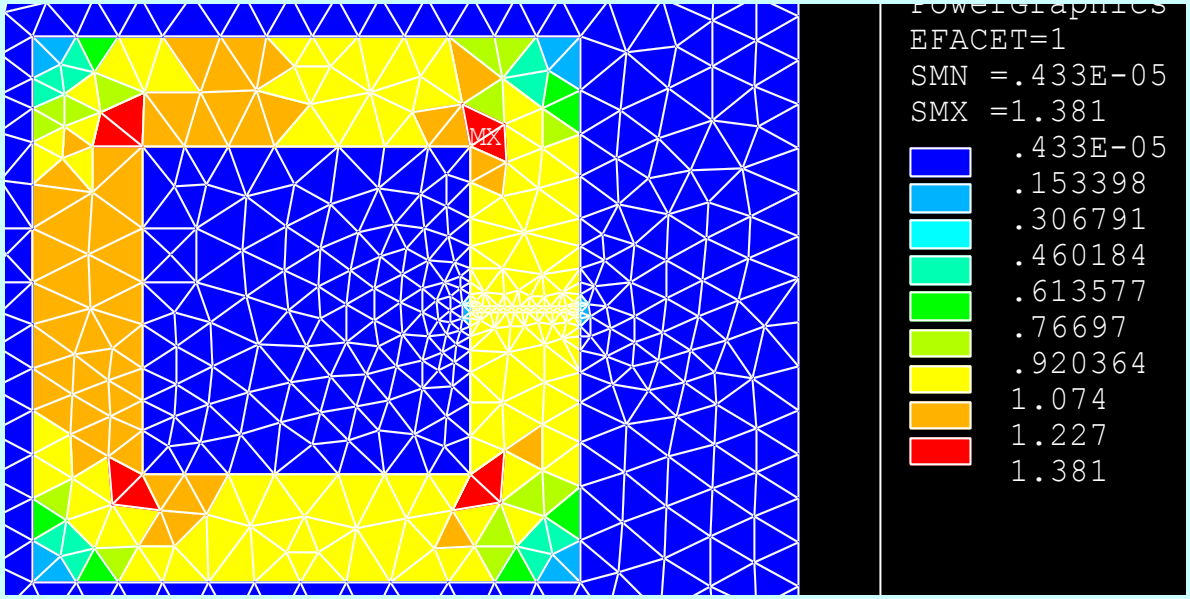
Permeabilidade do ferro fixa



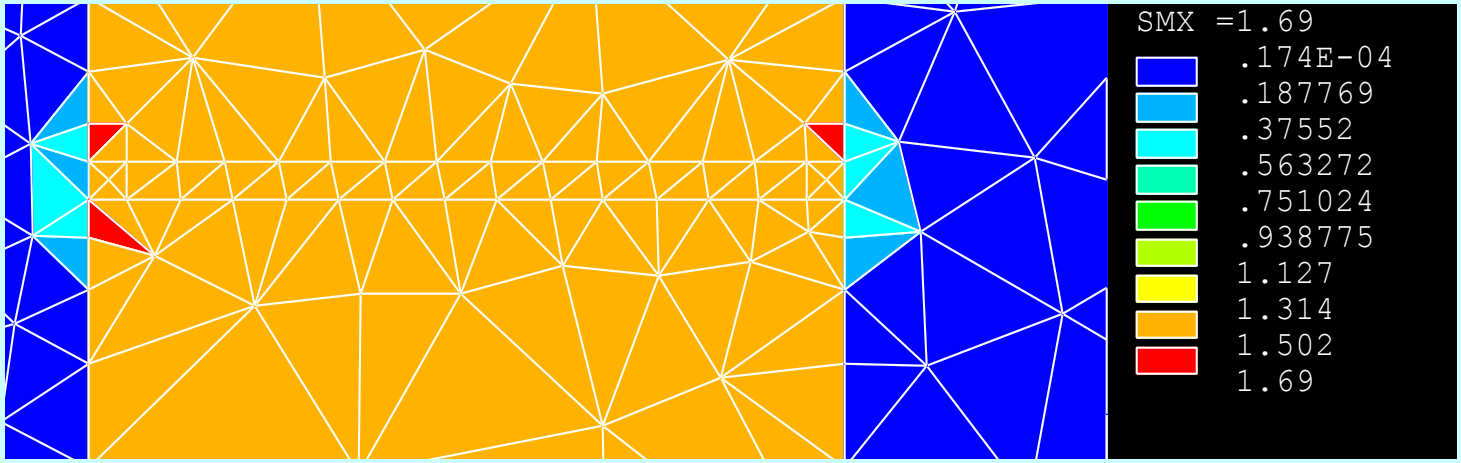


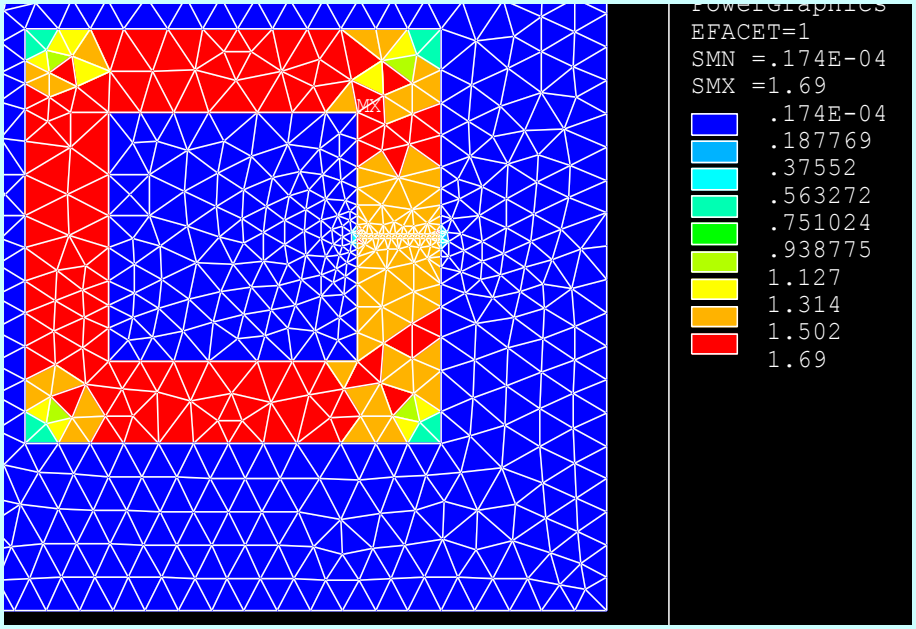
Curva de saturação

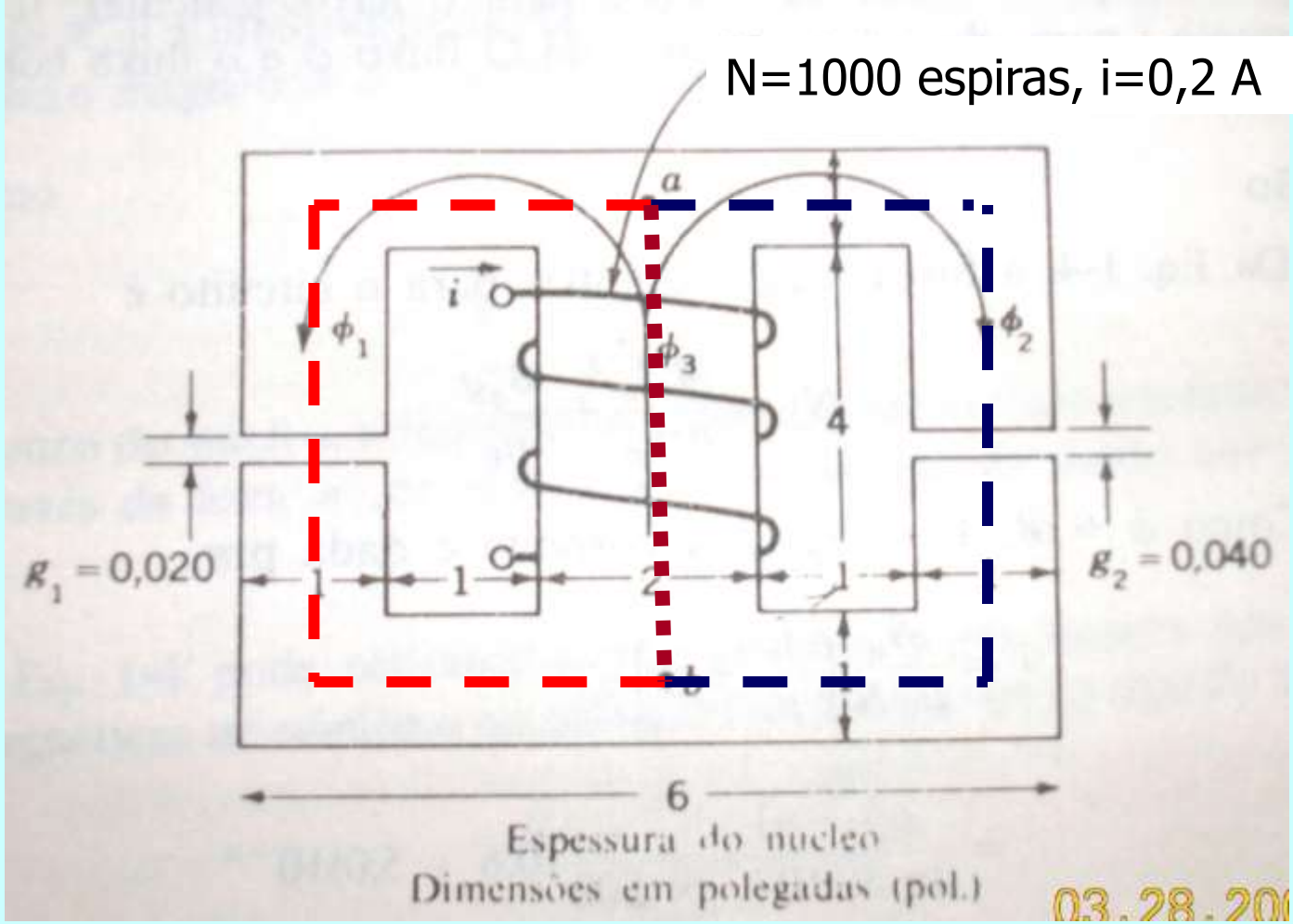




Duplicando a corrente

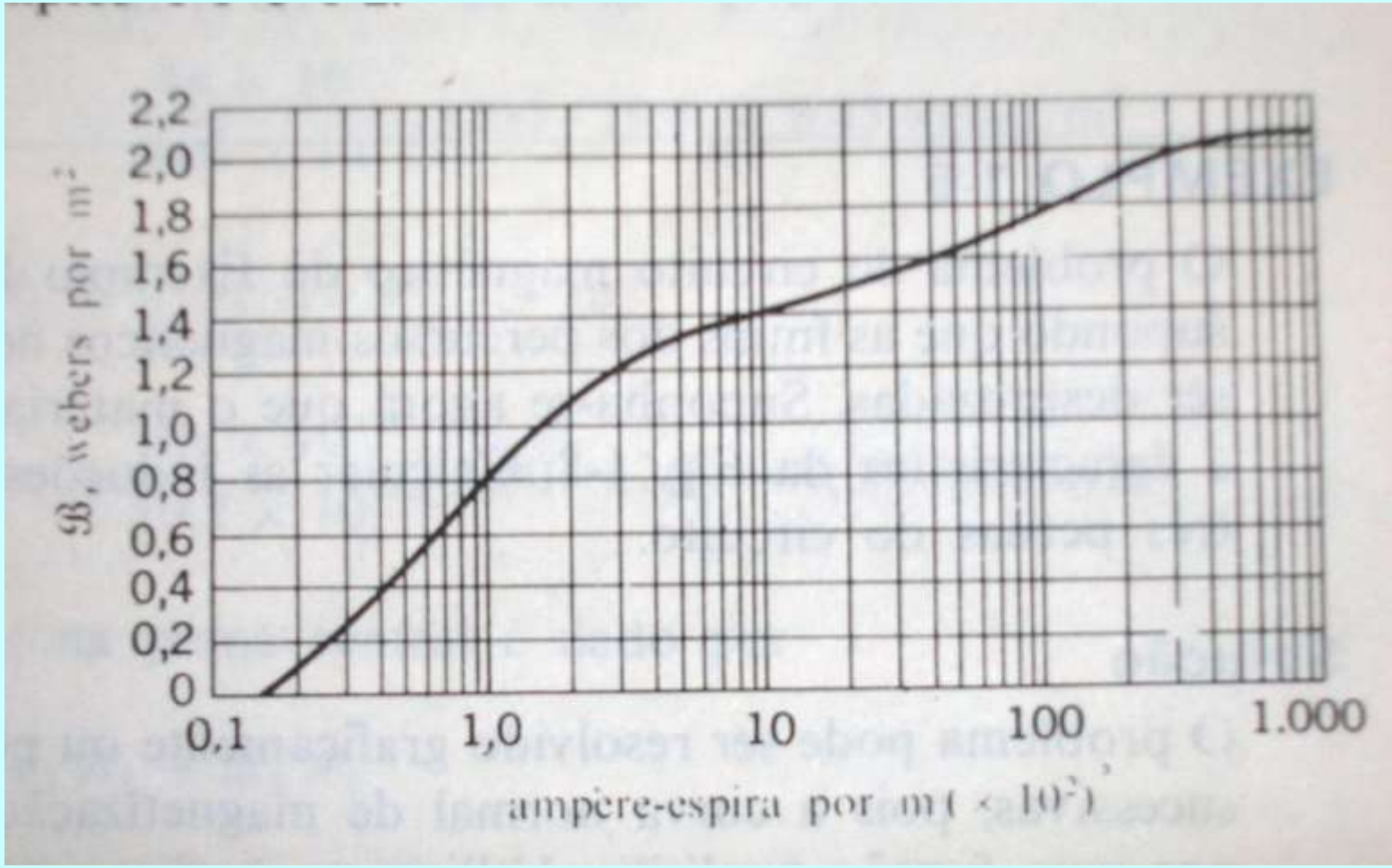






L1=**L2**=10 pol. **L3**=5pol.

Calcular B em cada entreferro.


2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0
0,1
1,0
10
100
1.000