problemen

- oude transformatoren houden geen rekening met energie transitie
- Loading guide: duidelijk, maar onnauwkeurig. wordt alleen uitgegaan van bepaalde load frequentie (50 Hz)
  ↳ harmonische trillingen in de core
- verliezen aan de hand van BH-veld bepalen
- verschil tussen frequentie en tijdsdomein duidelijk

Antwoorden

- B-veld is gemodelleerd met bepaalde stroom in 2D om de hotspot te vinden

Stoppen

- Maxwell vergl.
  - ↳ zowel steady state als laag-frequentie forcing
  - ↳ verwaarloos verplaatsingsstroom (geen 2e afgeleide naar de tijd)
- AFE
  - ↳ Mesh constructie: zie github (GMSH)
-

$$-\nabla \cdot [c \nabla u] + \sigma \frac{\partial u}{\partial t} = f(x,y,t)$$

zorgt voor problemen (want niet lineair)

↳ twee aanpakken

① sep. of vars $u = \hat{u}(x,y) \cdot e^{i\omega t}$ → freq domein

② of tijd als domein (zie werk van Lieke v. der Linde: multirate time integration).

③ welk van deze twee aanpakken is het meest voordelig

- installeren Julia
- installeren GMSH via Julia (zie Github hiervoor)

- zie code van Gijs
- thesis v. Max
- veranderen tekst voor tijdsdomein,

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Transient Problem Formulation

- Maxwell equations

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = J + \frac{\partial D}{\partial t}$$

$$\nabla \cdot B = 0$$

$$\nabla \cdot D = \rho$$ — free charge density (~10)

$E :=$ electric field intensity

$B :=$ magnetic flux density

$J :=$ current density

$H :=$ magnetic field intensity

$D :=$ is the electric flux density

$J_e :=$ external current density (passing through a surface)

$J_{cond} :=$ conductive current density (amount of current on a surface)

- Constitutive relations

$$J = J_e + J_{cond}$$

$$B = \mu H$$

$$J_{cond} = \sigma E$$

$$D = \epsilon E \quad \text{(very small)}$$

- Substituting the constitutive relation and neglecting electric flux density gives

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times (\mu^{-1} B) = J_e + \sigma E$$

$$\nabla \cdot B = 0$$

- Assuming potential formulation

$$\boxed{B = \nabla \times A}$$

$$\boxed{E = -\nabla \varphi - \frac{\partial A}{\partial t}}$$

any twice diff. scalar field, we choose $\varphi = 0$

- 2D case

$$A = (0, 0, A_z(t, x, y))$$

$$J_e = (0, 0, J_z(t, x, y))$$

$$\boxed{-\frac{\partial}{\partial x}\left(\mu^{-1}\frac{\partial A_z}{\partial x}\right) - \frac{\partial}{\partial y}\left(\mu^{-1}\frac{\partial A_z}{\partial y}\right) + \sigma \frac{\partial A_z}{\partial t} = J_z}$$

- IBVP

no flux through the boundaries

$$B \cdot n = 0$$

$$0 = (\nabla \times A) \cdot n = \nabla \cdot (n \times A) = n \times A = 0$$

Initial potential field is zero

$$A(0, x) = 0$$

Coil excitation

$$J_e = \frac{N I_{coil}}{A} e_{coil} \quad (*)$$

N: number of turns per winding
I_{coil}: coil current
A : area of winding
e_{coil} : vector excitation direction

→ current driven

I_{coil} is specified

→ Voltage driven

$$V_{tot} = I_{coil} R_{coil} + V_{ind}$$

$$V_{ind} = \frac{1}{A} \iint_A (E \cdot e_{coil}) \cdot N \cdot L \, dA$$

$$R_{coil} = \frac{1}{A} \iint_A \frac{N \cdot L}{\sigma_{coil} a_{coil}} \, dA$$

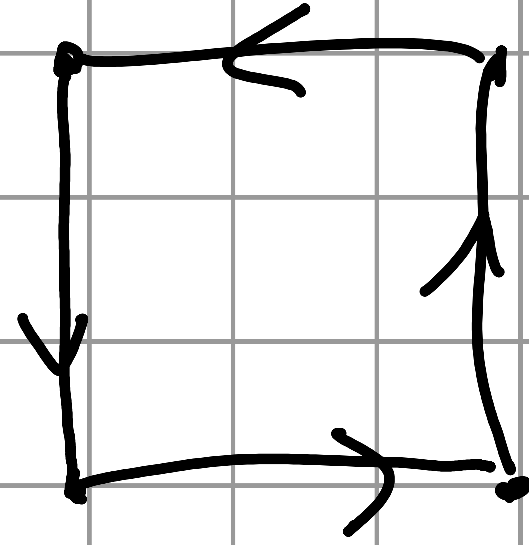
in 2D $V_{tot} = \frac{1}{A} \iint_A E_z \cdot N \cdot L \, dA$

V_{tot}: total voltage (imposed)
V_{ind}: induced voltage
R_{coil}: resistance of coil
L : out of plane thickness
σ_{coil}: coil wire conductivity
a_{coil} : coil wire cross-sectional area

suoshiulvg $\otimes$ in

Geometry definition

← loop over points



1. punten
2. lijnen
3. oppervlakten

pre processing

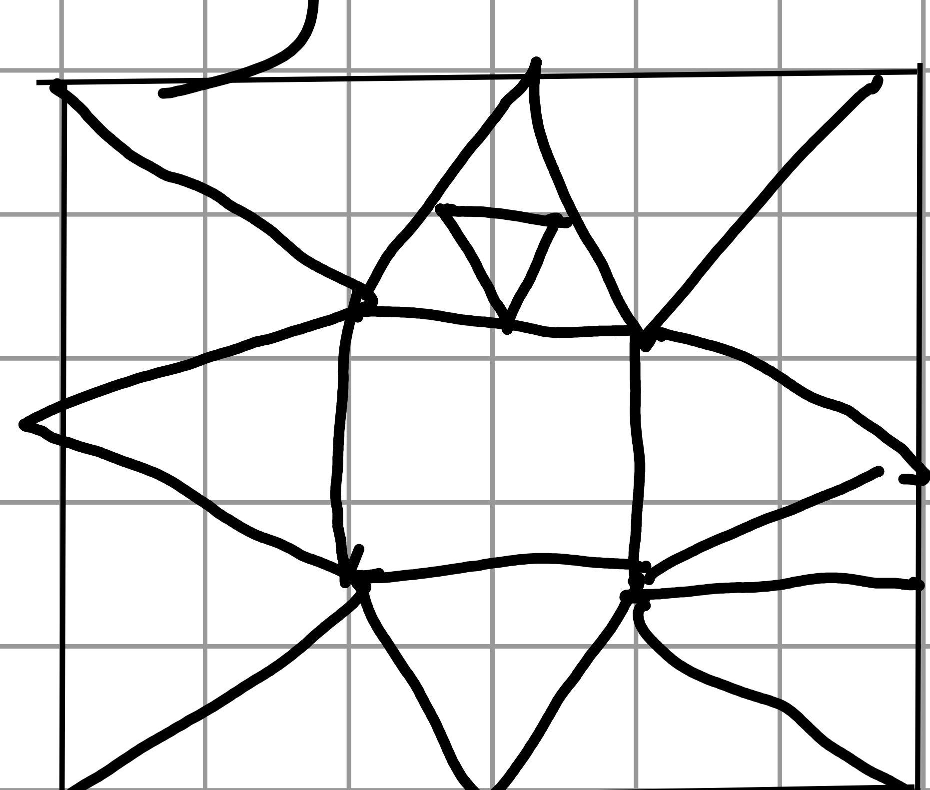
Mesh definition

After geometry definition

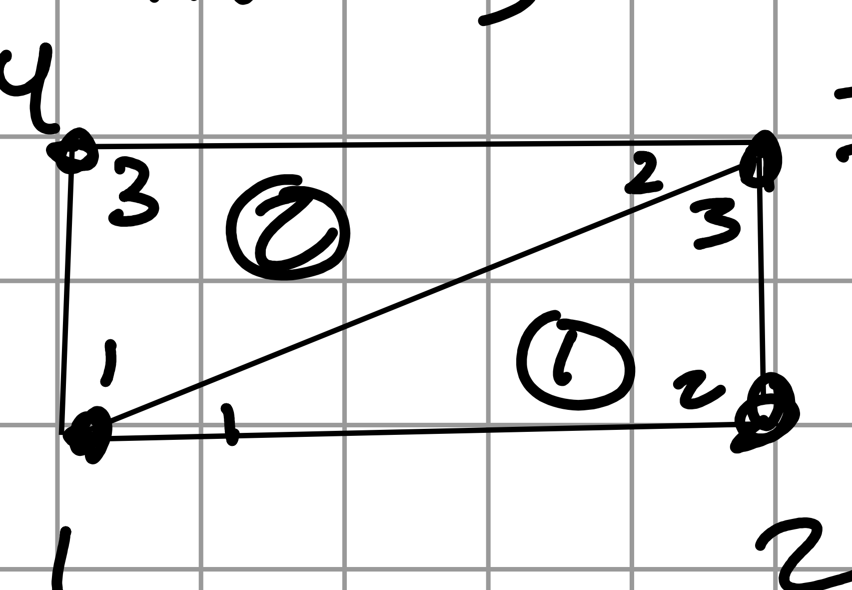
takes boundaries into account

processing

Assembly



connectiviteits matrix



PDE $\longrightarrow$ Weak form $\rightarrow$ FE-discr.

$\longrightarrow \quad A\underline{u} = f$

post

Visualisatie

Paraview

Transient

$$\sigma \frac{\partial A_z}{\partial t} = \nabla \left(\frac{1}{\mu} \nabla A_z \right) + f(x,y)$$

↳ freq domain

$$[j\omega\sigma M + \tfrac{1}{\mu} A] u = f$$

↳ full formulation

$$\overbrace{\sigma M}^{\text{diagonal}} \dot{\underline{u}} = \frac{1}{\mu} A \underline{u} + \underline{f} \qquad \text{(ODE)}$$

(zouden we deze hebben voor ons voorbeeld)

freq v time formulations

multiple frequencies present cause superposition to break down

↳ Do we number u as

ask STEAM for frequencies

$$u = \hat{u}_1(x,y)\, e^{j\omega_1 t} + \hat{u}_2(x,y)\, e^{j\omega_2 t} + \ldots$$

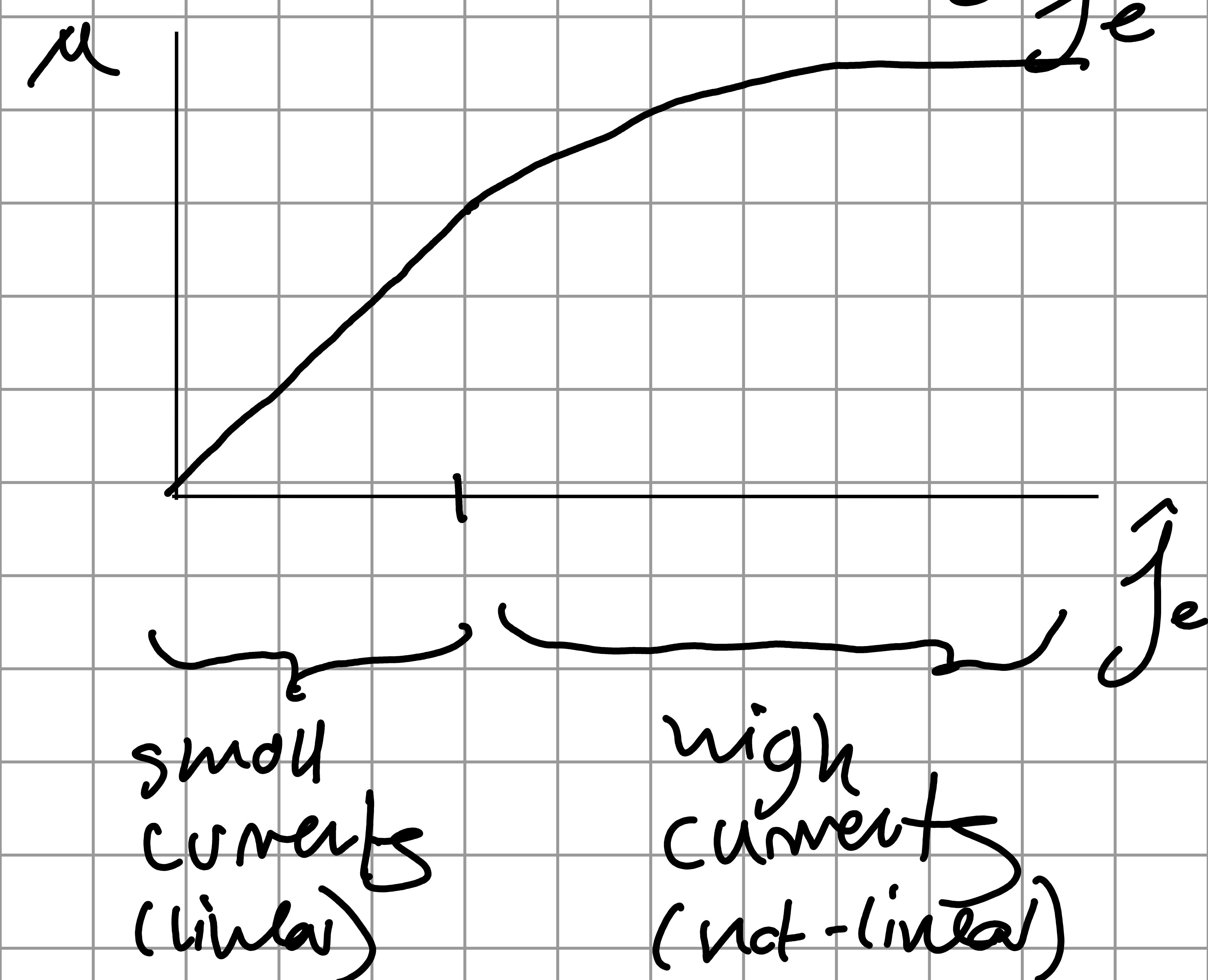
↳ or do we cut our losses and switch to a full time domain analysis,

What about μ?

↳ linear : $\mu := \mu_{FE}$ (constant)

superposition is still possible

↳ non-linear : $\mu = \mu_{FE}$ (geldig voor kleine $\hat{J}_e$)



?: what is the effect of non-linear μ on superposition, as the frequencies start to become coupled.

Stationary Maxwell

$$\nabla \times \left(\frac{1}{\mu} \nabla \times A \right) = J \qquad \text{(general)}$$

if we suppose 2D domain we get eq 5.18 in Max's thesis

furthermore

$$\underline{B} = \nabla \times A =$$

$$B_z = \frac{\partial}{\partial y} A_z \quad , \quad B_y = - \frac{\partial}{\partial y} A_z$$

$$\|B\| = \sqrt{B_x^2 + B_y^2 + B_z^2} = \sqrt{A_{z,y}^2 + A_{z,x}^2}$$

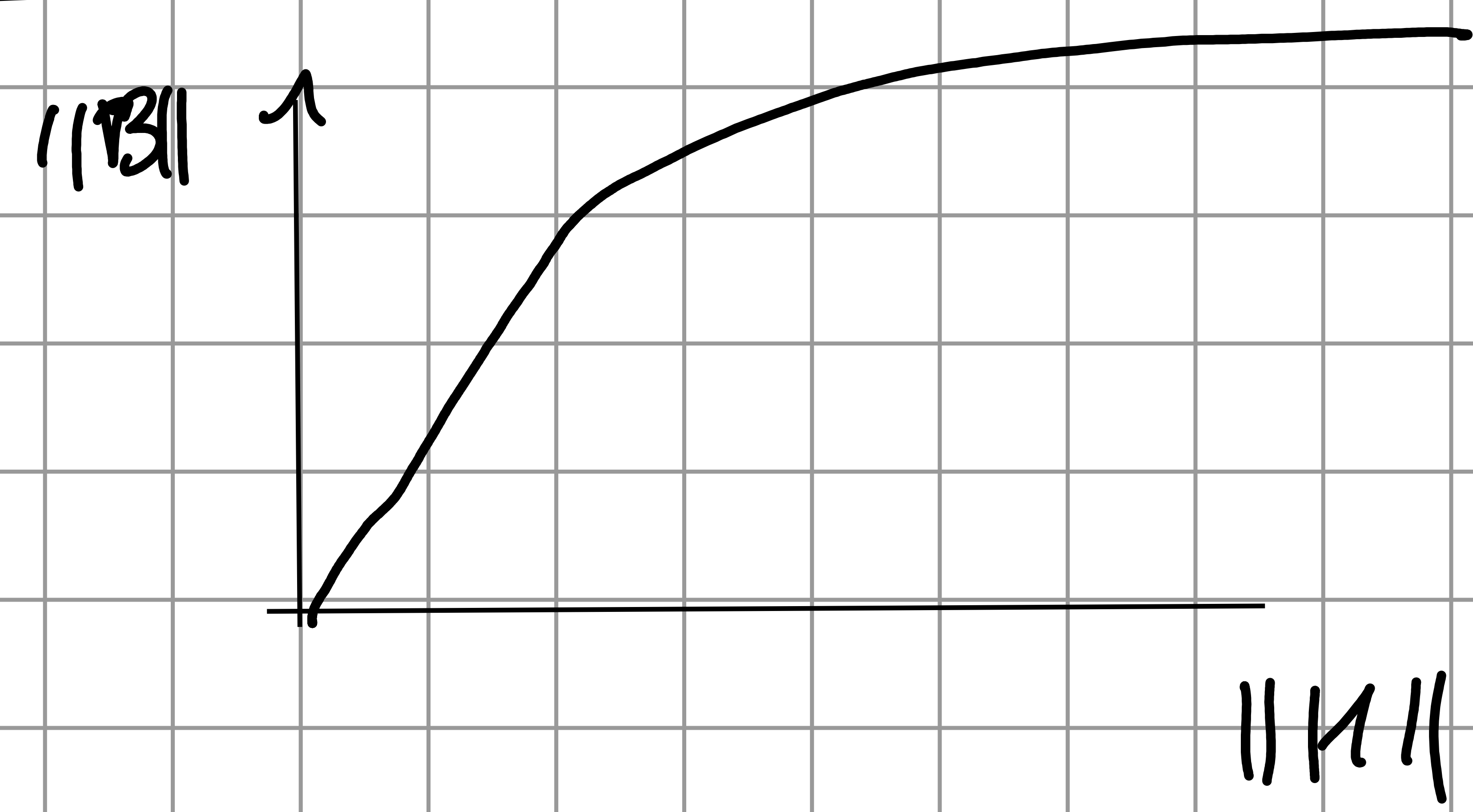
$$= \| \nabla A_z \|$$

$$H = \frac{1}{\mu} B$$

$$H_x = \frac{1}{\mu} A_{z,y}$$

$$H_y = \frac{1}{\mu} \left[- A_{z,x} \right]$$

BH- veld



$\mu(||B||)$ = richting van de raaklijn aan de B-H kromme in ||B||

Analyse van de oplossing

- We willen de oplossing tijdens de piek belasting bekijken
- dit hoeft niet langer dan +/- 30 min

Calculation of local contribution

bases

$$\varphi_i^e = a_i x_i + b_i y_i + c_i$$

must satisfy

$$\begin{pmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{pmatrix} \underbrace{\begin{pmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{pmatrix}}_{\text{Emat}} = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}$$

To calculate stiffness contribution

$$\nabla \times \left(\frac{1}{\mu} \nabla \times A_z \right)$$

set constants c_i to zero (they cancel due to the derivative).

$$\text{Emat}[3,:] .= 0$$

then

$$\text{Emat}[3,:]^T \, \text{Emat}[3,:] = (a_i a_j + b_i b_j)_{1 \le i,j \le 3}$$