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# Static Hysteresis modelling of FeSi NO sheets in rolling and transverse directions

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## Context and objectives

1. predict magnetic losses or magnetic waveforms in NO FeSi sheets when excited in both rolling (RD) and transverse direction (TD).
2. Need for a vectorial hysteresis model
3. Modification of the vector play model [1] improved by [2]

## Original isotropic Model

$$\mathbf{h} = \mathbf{h}_{re} + \mathbf{h}_{ir} \quad (1)$$

$$\mathbf{h}_{re} = \sum_{k=1}^N \omega_k \mathbf{h}_{re}^k \quad (2)$$

$$\mathbf{h}_{re}^k = \begin{cases} \mathbf{h}_{re0}^k & \text{if } \|\mathbf{h} - \mathbf{h}_{re0}^k\| < \chi^k \\ \mathbf{h} - \chi^k \cdot \frac{\mathbf{h} - \mathbf{h}_{re0}^k}{\|\mathbf{h} - \mathbf{h}_{re0}^k\|} & \text{otherwise} \end{cases} \quad (3)$$

$$\mathbf{M} = M_{an}(\|\mathbf{h}_{re}\|) \cdot \frac{\mathbf{h}_{re}}{\|\mathbf{h}_{re}\|} \quad (4)$$

$$\mathbf{b} = \mu_0(\mathbf{M} + \mathbf{h}) \quad (5)$$

- $\chi^k$ : maximum pinning field of the  $k^{th}$  cell
- $\omega_k$ : weight of the  $k^{th}$  cell

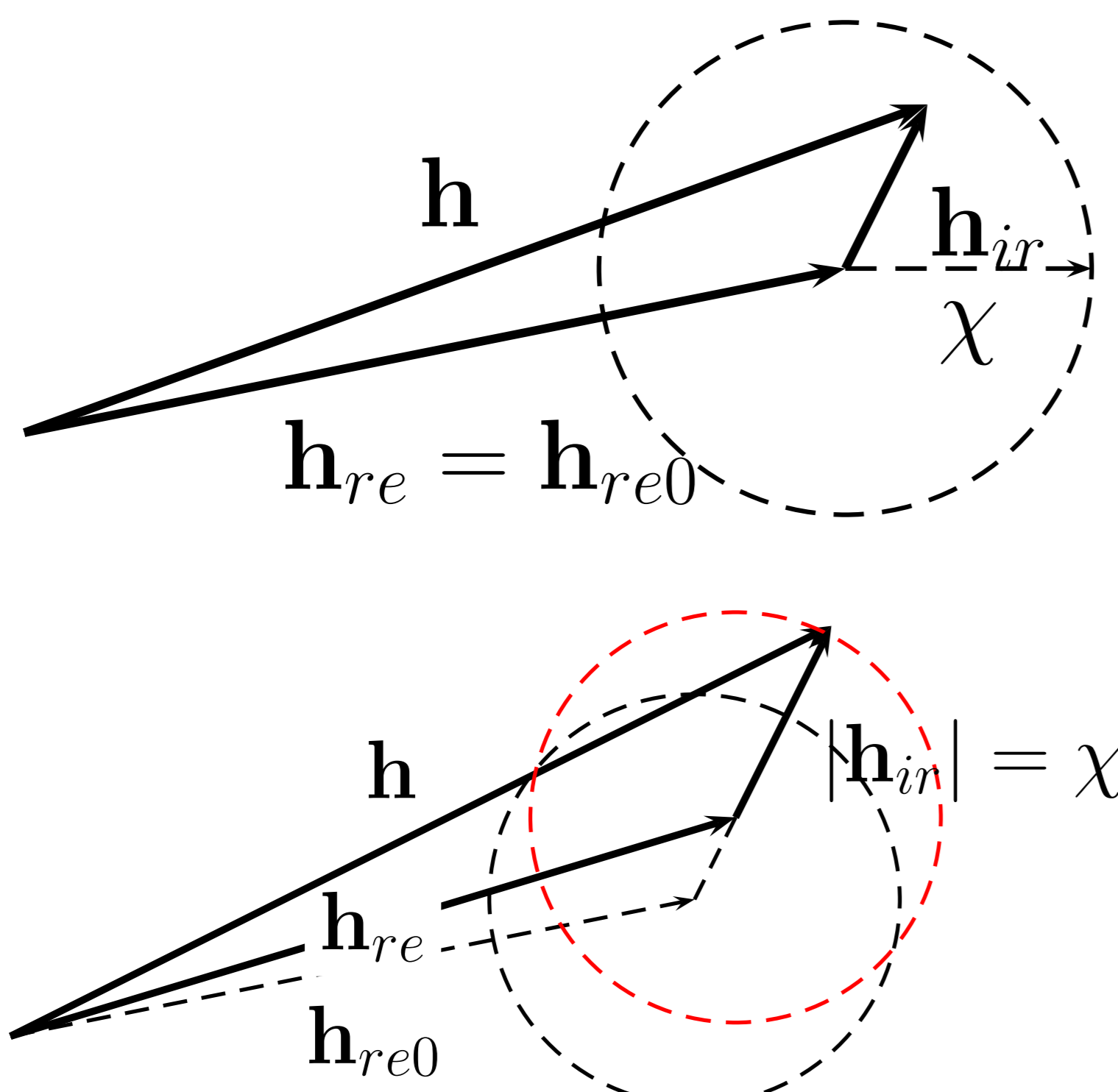


Figure 1: Example of the two situations of (3)

## Modifications to include anisotropy

Modifications proposed in [3] to take into account magnetic anisotropy in FeSi NO sheets.

1. Modifications of the anhysteretic curve (4)

$$\mathbf{M} = M_{an}(\|\mathbf{h}_{re}\|) G(\gamma) \frac{\mathbf{h}_{re}}{\|\mathbf{h}_{re}\|} \quad (6)$$

with  $\gamma$ , a scalar parameter to identify

$$G(\gamma) \frac{\mathbf{h}_{re}}{\|\mathbf{h}_{re}\|} = \begin{bmatrix} 1 & 0 \\ 0 & \gamma \end{bmatrix} \begin{pmatrix} e_{RD} \\ e_{TD} \end{pmatrix} \quad (7)$$

2. Modifications of the coercivity (pinning field) by making cells ellipsoidal.

$$\chi^k(\alpha, \beta) = \chi_{RD}^k (1 + (\beta - 1)(1 - \alpha^2)) \quad (8)$$

with :

- $\beta$  : a scalar parameter to determine
- $\chi_{RD}^k$  : pinning field of the  $k^{th}$  cell in RD.
- $\alpha$  : cosine of the angle between  $\mathbf{h} - \mathbf{h}_{re0}^k$  and  $\mathbf{e}_{RD}$

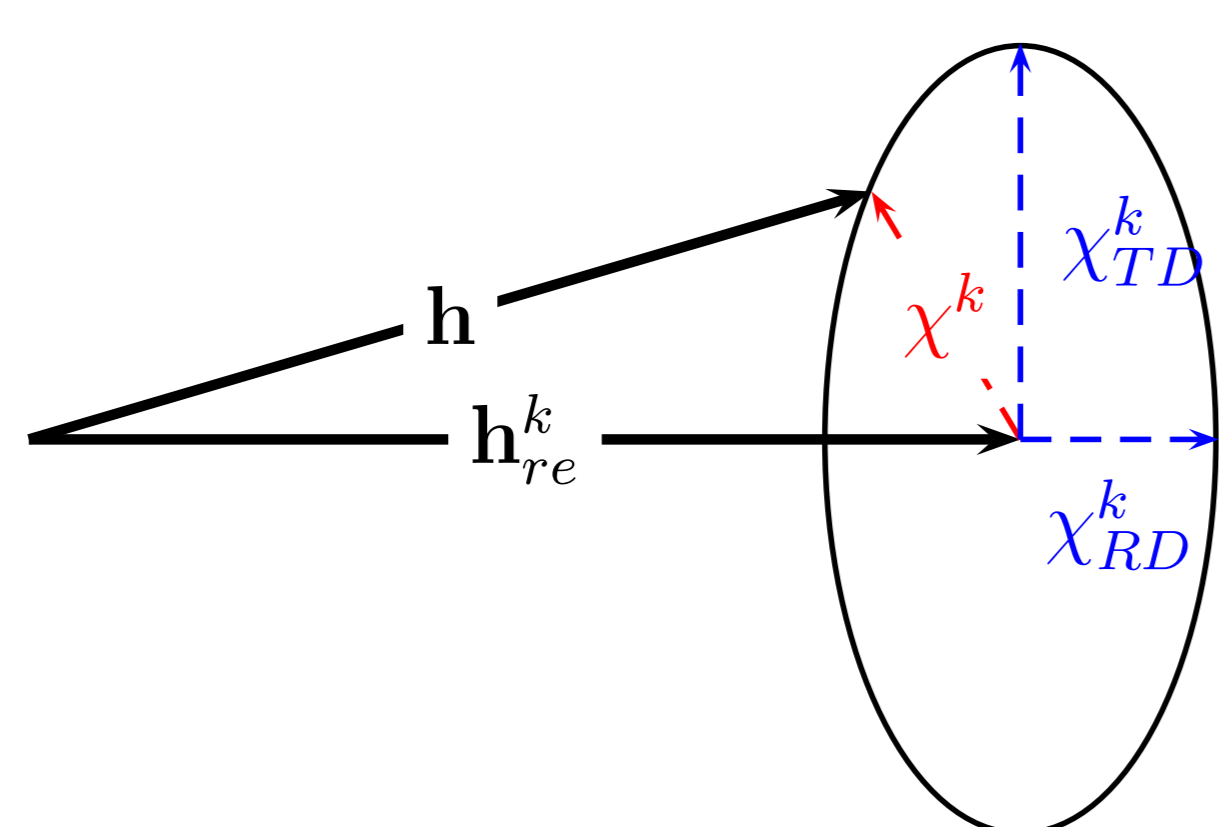


Figure 2: Illustration of ellipsoidal spheres

## Tested material and methods

- FeSi 3%wt 0.5 mm thick non oriented material
- Characterizations have been made by CADEMA group from Torino for the TEAM32 problem [4]
- Several static loops were measured on Epstein device along different angles with respect to RD for different amplitudes.
- Loops measured at RD and TD are used for tests and identification of parameters.
- Loops at intermediate directions are only used for tests.

## Identification Results

the  $(\omega_k, \chi^k)$  sets have been identified following the protocol described in [5].

Table 1: Values of  $\omega_k$  and  $\chi^k$  sets in RD

$\omega_k$	0.021	0.237	0.3954	0.1681	0.1773
$\chi^k$	0	25.1	51.2	70.4	127.7
$\gamma$	0.965				$\beta$ 1.3

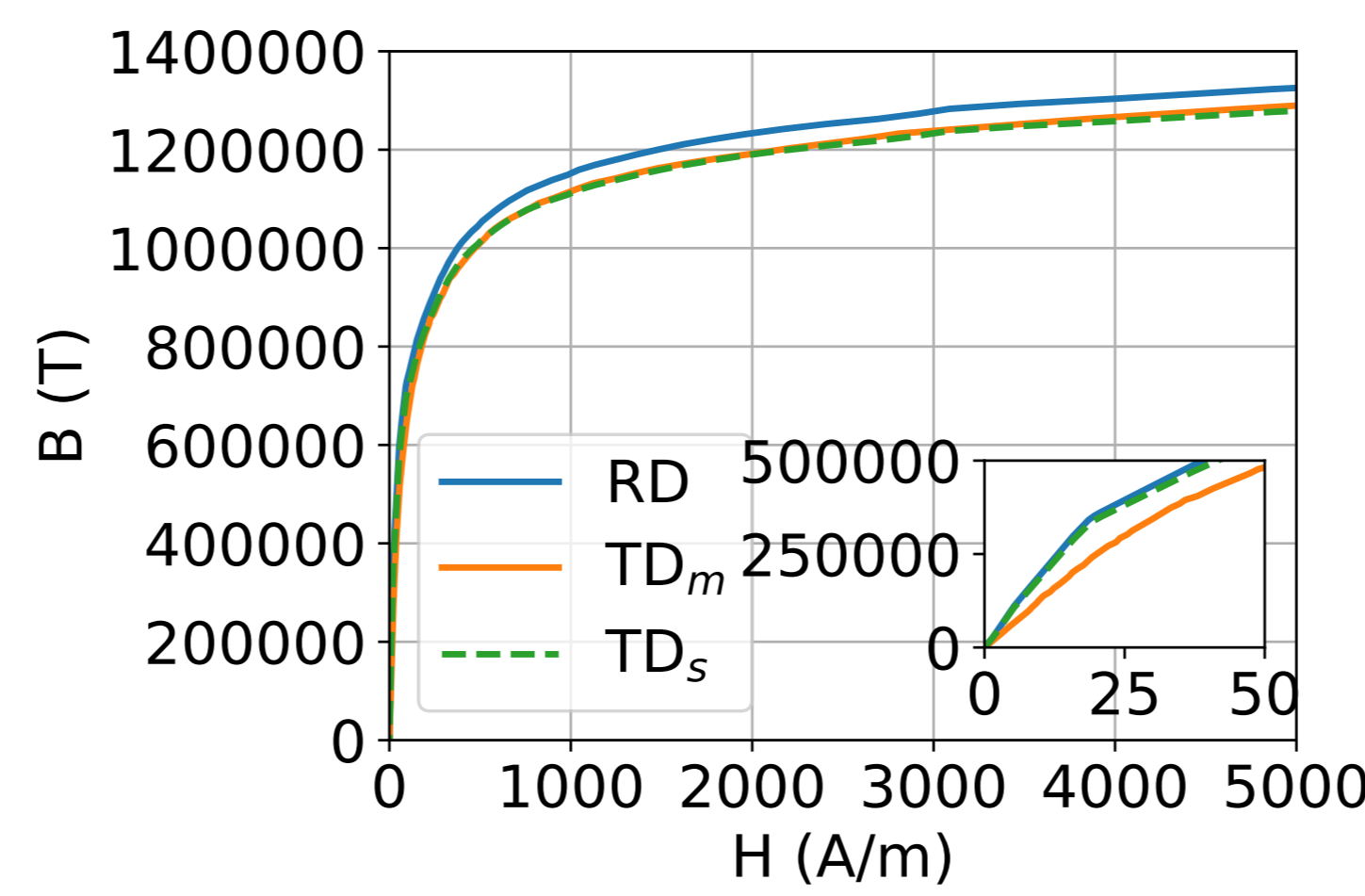


Figure 3: Measured and simulated anhysteretic functions in RD and TD

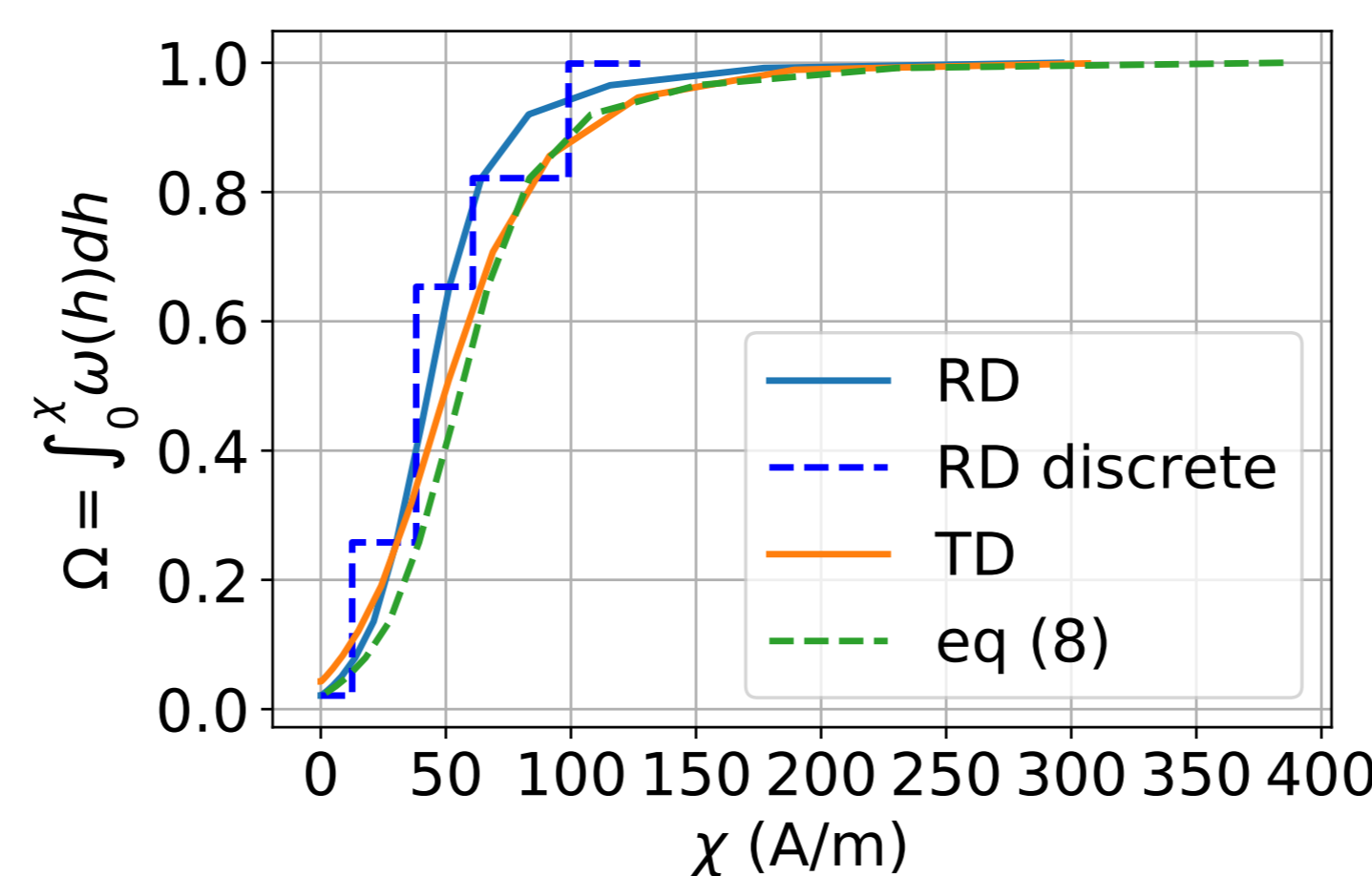


Figure 4: Cumulative distribution of the weights versus pinning field in RD and TD and result of eq (8)

## Example of results

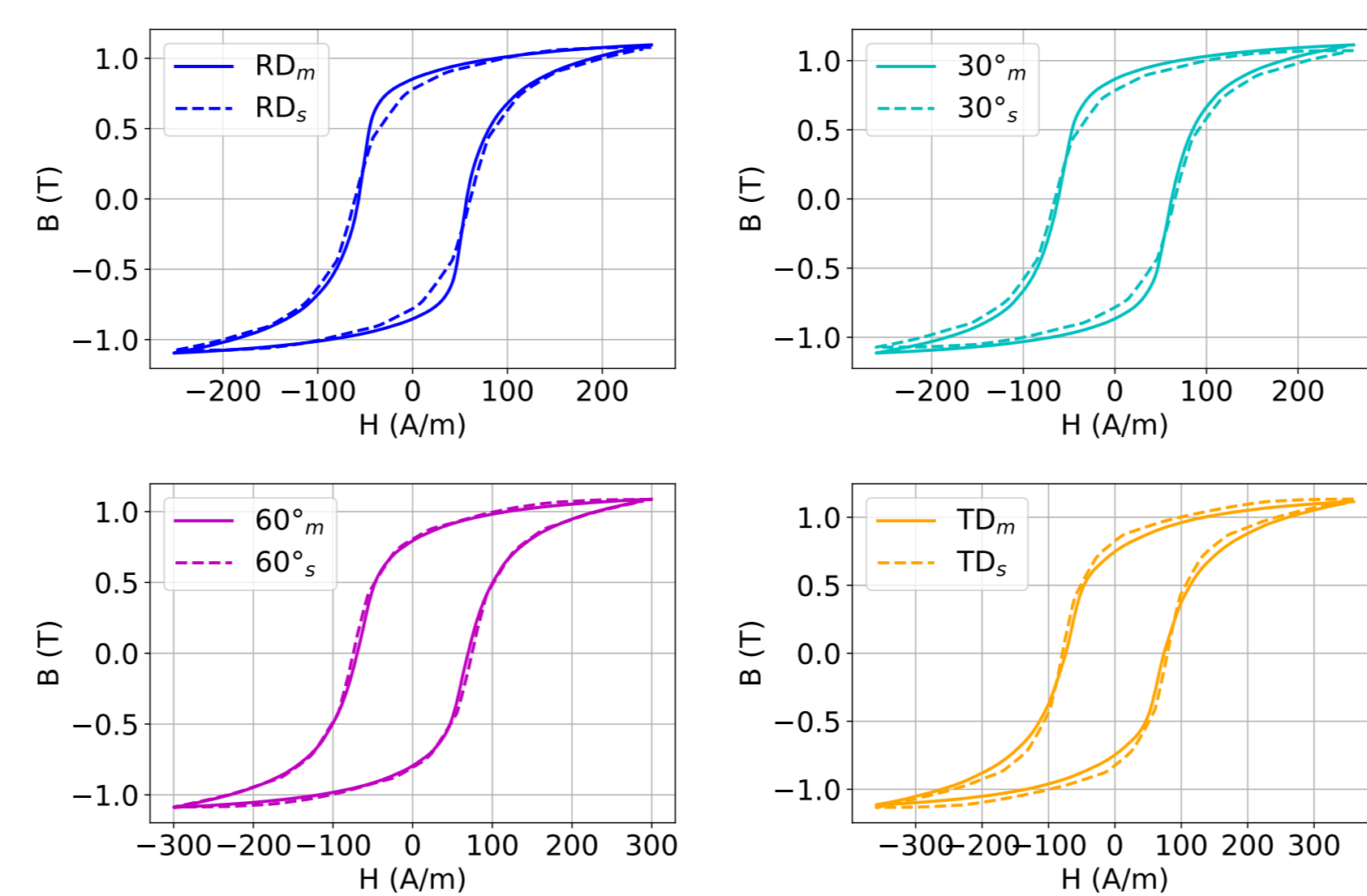


Figure 5: Comparison of measured and simulated loops at 1.1 T for different angles

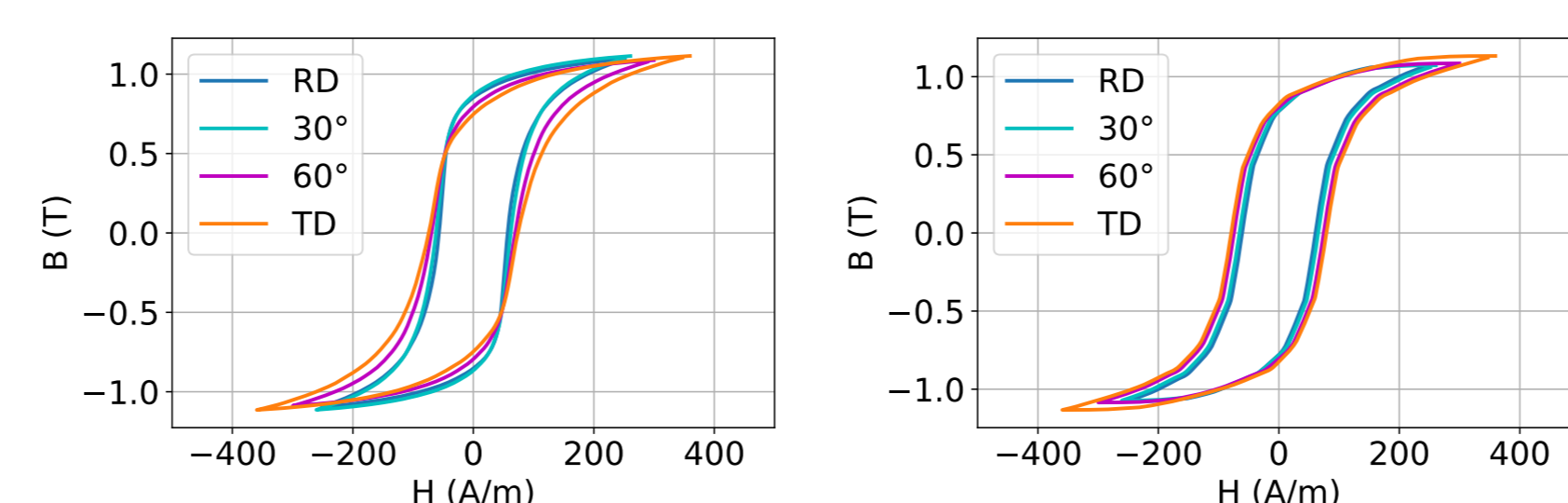


Figure 6: Measured (left) and simulated (right) loops at 1.1 T for different angles

## Accuracy analysis of the loops

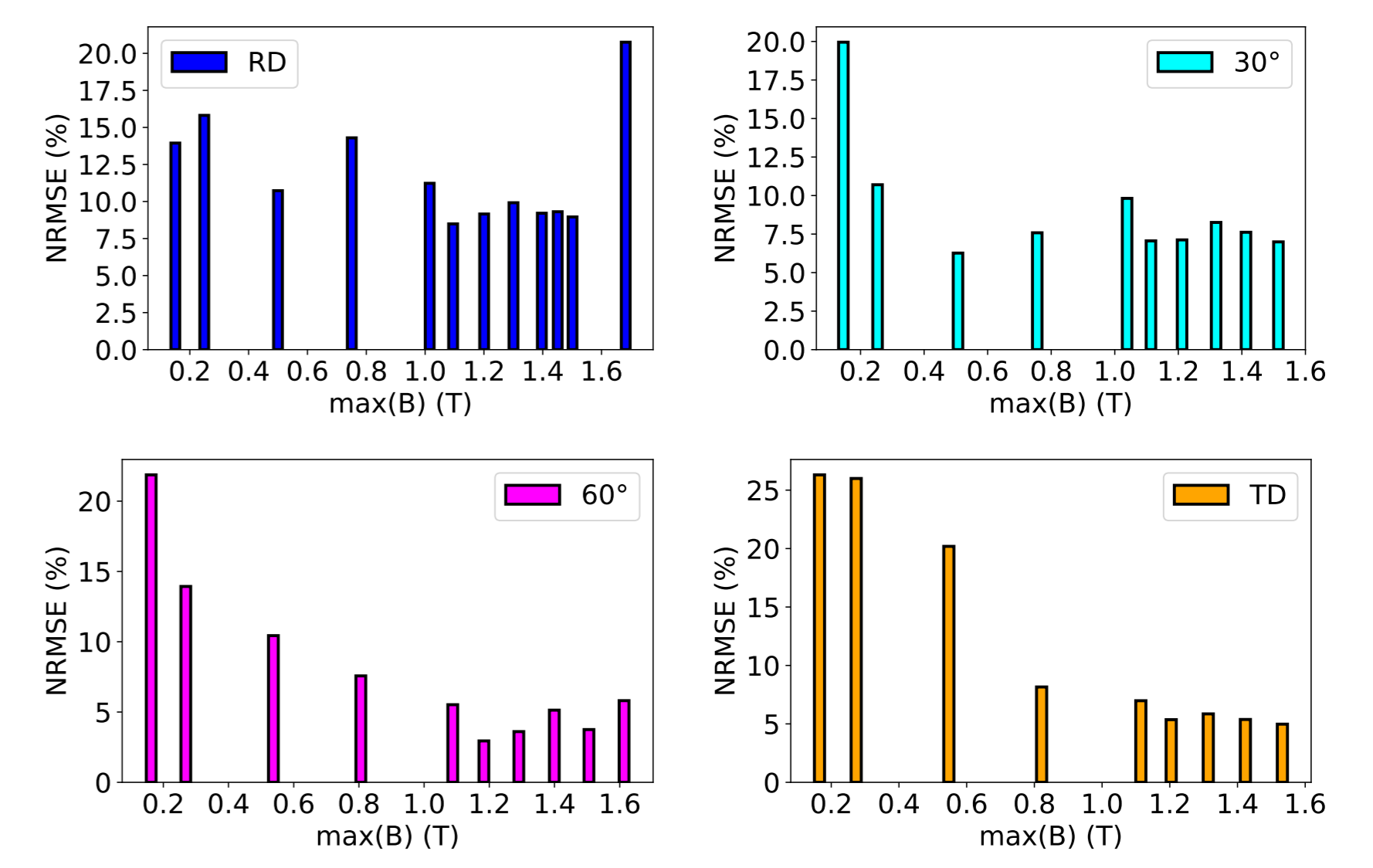


Figure 7: Accuracy versus amplitude of the loops in each direction

## behavior of the losses vs angle

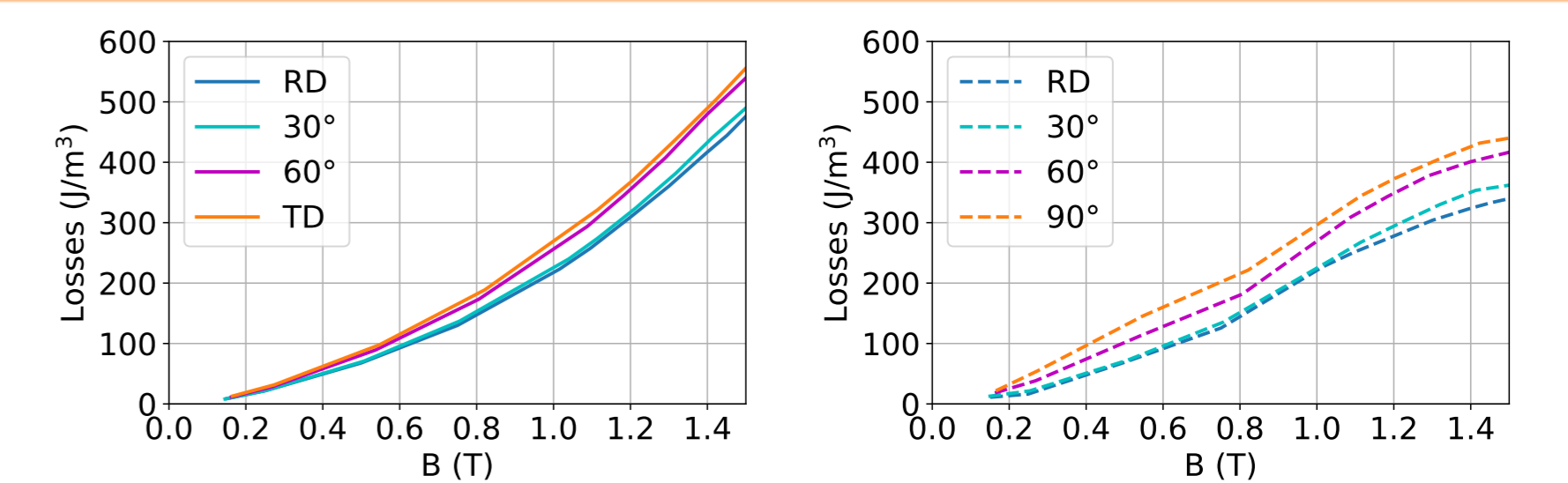


Figure 8: Measured (left figure) and simulated (right figure) losses vs  $B_{max}$  for different angles

## Discussion

- Accuracy in RD is not so good for two reasons:
  - coercivity can not be considered as constant along the  $M_{an}(H_{an})$  curve.

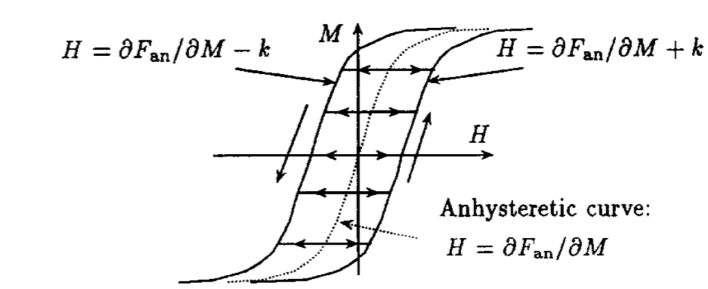


Figure 9: Assumption to respect [1]

- identification of first cells following [5] may be inaccurate. Following [6] can improve accuracy in this region as recently shown in [7].
- Proposed modifications are sufficient to qualitatively take into account of the anisotropy
- Losses behaviour vs angle is qualitatively well retrieved. Accuracy of computed losses should be improved.

## Conclusions and perspectives

- A readily vectorial hysteresis model including anisotropy has been tested.
- Better identification of  $(\omega_k, \chi^k)$  or/and improvements of the original model must be made (constant coercivity assumption) for FeSi materials
- More complex modifications can be imagined to improve the accuracy such as
 
$$\mathbf{M} = \begin{pmatrix} M_{anRD}(\|\mathbf{h}_{re}\|) \\ M_{anTD}(\|\mathbf{h}_{re}\|) \end{pmatrix} \frac{\mathbf{h}_{re}}{\|\mathbf{h}_{re}\|} \quad (9)$$
- inverse the model to have  $\mathbf{h}(\mathbf{b})$
- Test this approach with FeSi GO materials

## References

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