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INDUSTRY NAVIGATOR

INVESTMENTS, ARTIFICIAL INTELLIGENCE  
AND SUSTAINABILITY  
CONFERENCE 2024

# FRA winding type field cases and automatic classification using AI

Based on Transformers Magazine Special Edition: ML & AI paper  
Jean SANCHEZ, EDF  
David GOPP, Omicron

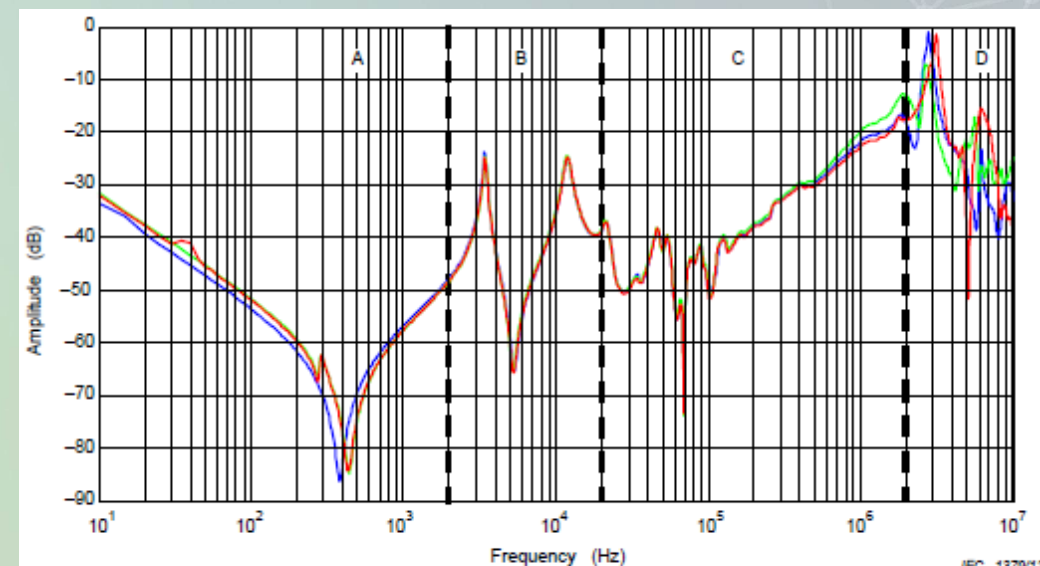
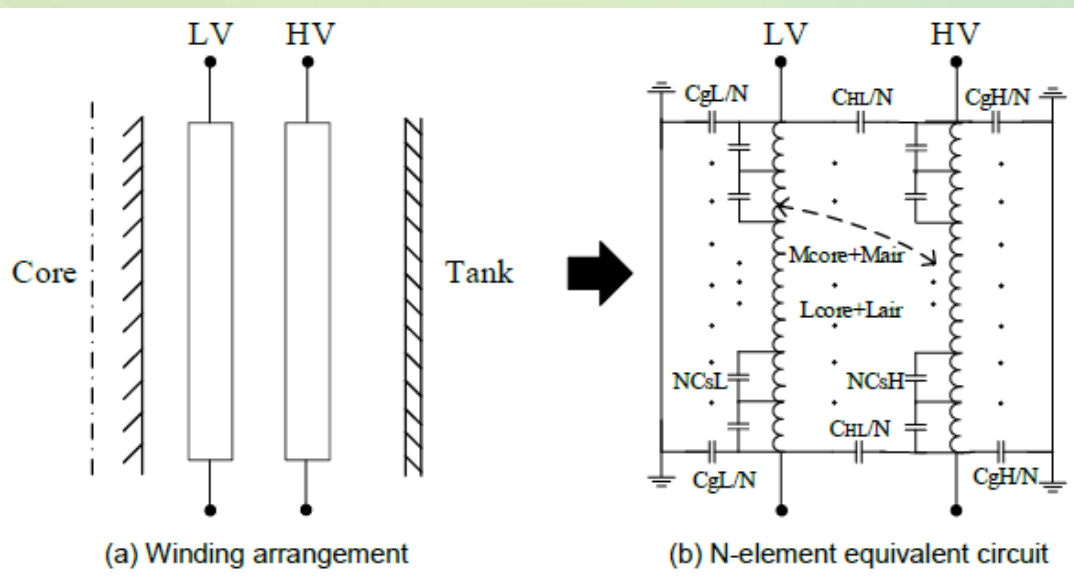
12/06/2024





# Frequency Response Analysis (FRA)

Transformer is a complex system of inductances, capacitances thus resonances over frequency  
=> FRA is a sensitive signature of a given design, especially the winding types  
=> Voltage ratio (in dB) between two terminals and phase shift measurements  
=> Like seeing into a “black box”



Influence regions:

- A core
- B interaction between windings
- C winding structure
- D measurement setup and lead (including earthing connection)

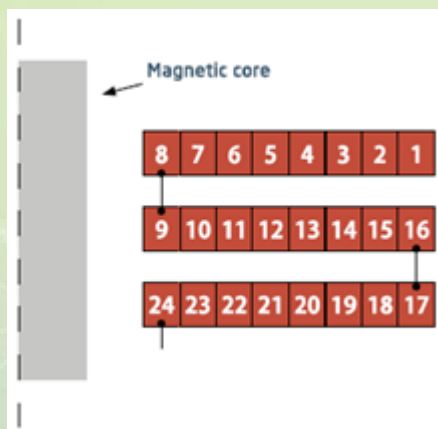
**Figure B.6 – General relationships between frequency response and transformer structure and measurement set-up for HV windings of large auto-transformer**



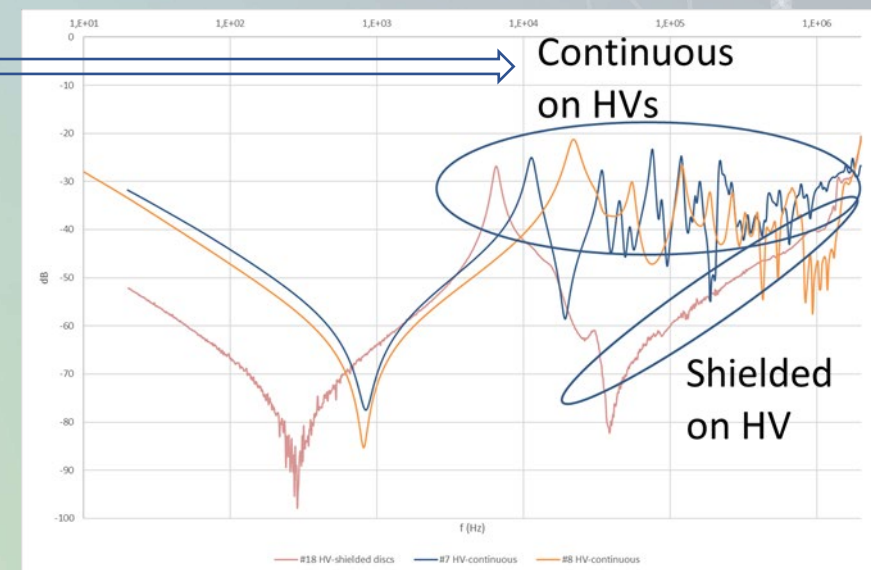
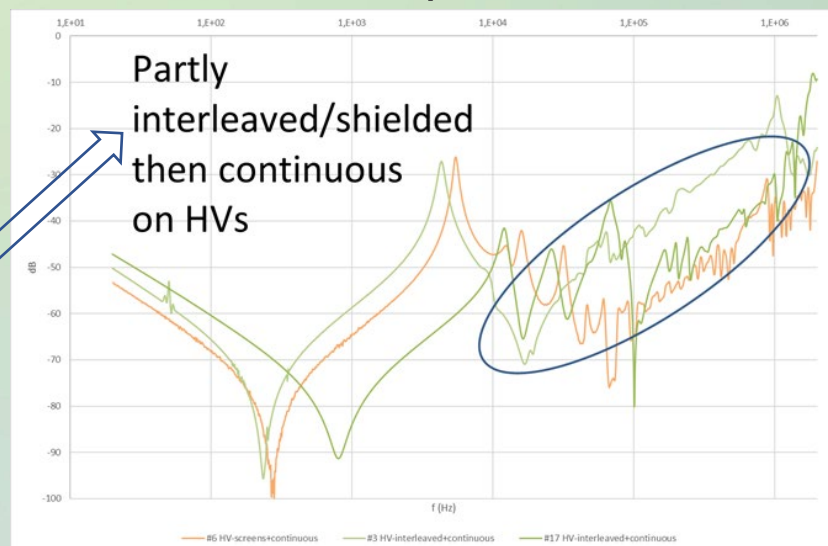
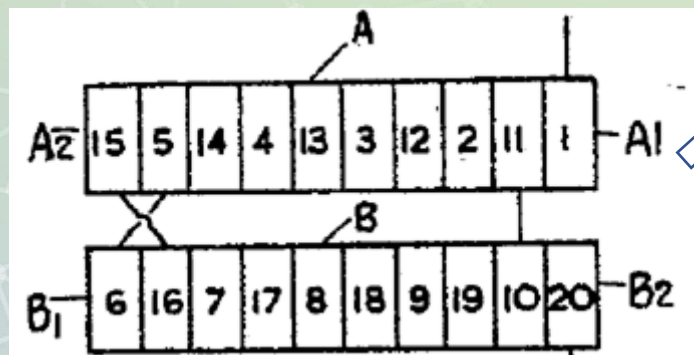
# FRA and winding types

Windings can have different designs... and FRA patterns!

=> Interesting for diagnosis. Risky... or not?: that is the question 😊



Easy to measure 😊  
Hard to understand ☹️  
Experts needed... or AI support in future?  
Let's try!





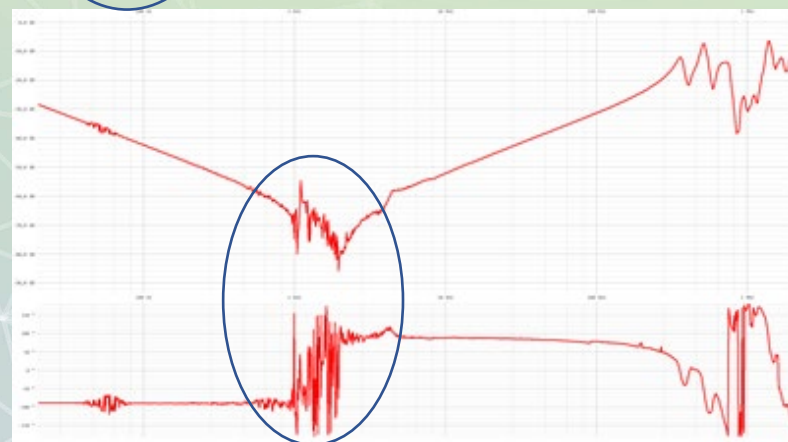


# FRA is sensitive...

Many factors can influence the measurements ☹ in that case AI classification needs expert knowledge!  
*at first... at least ☺*

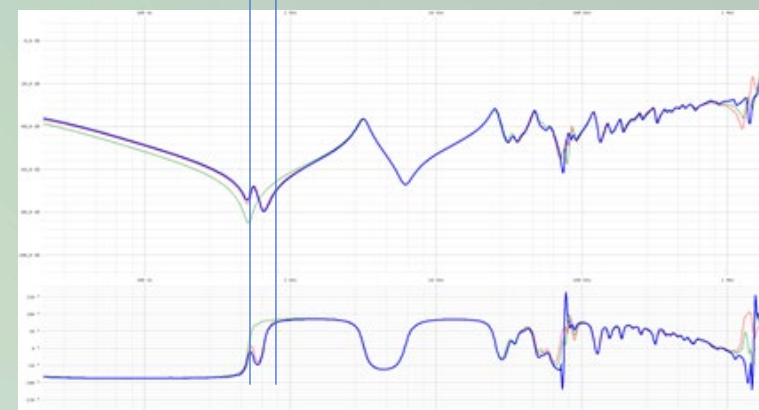
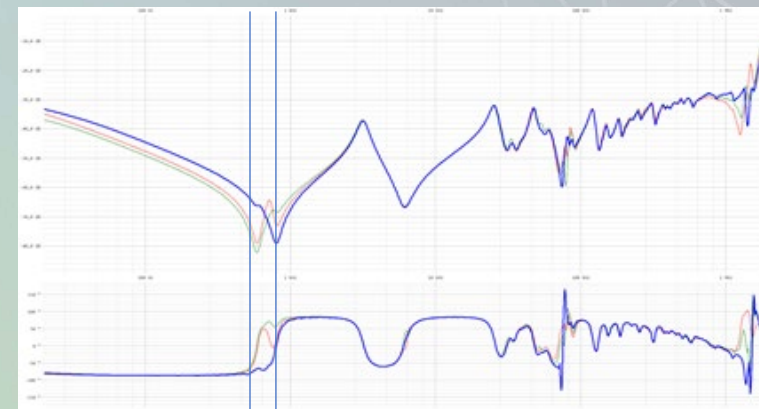


External influence



Bad dynamic range

Variation over  
a DC test

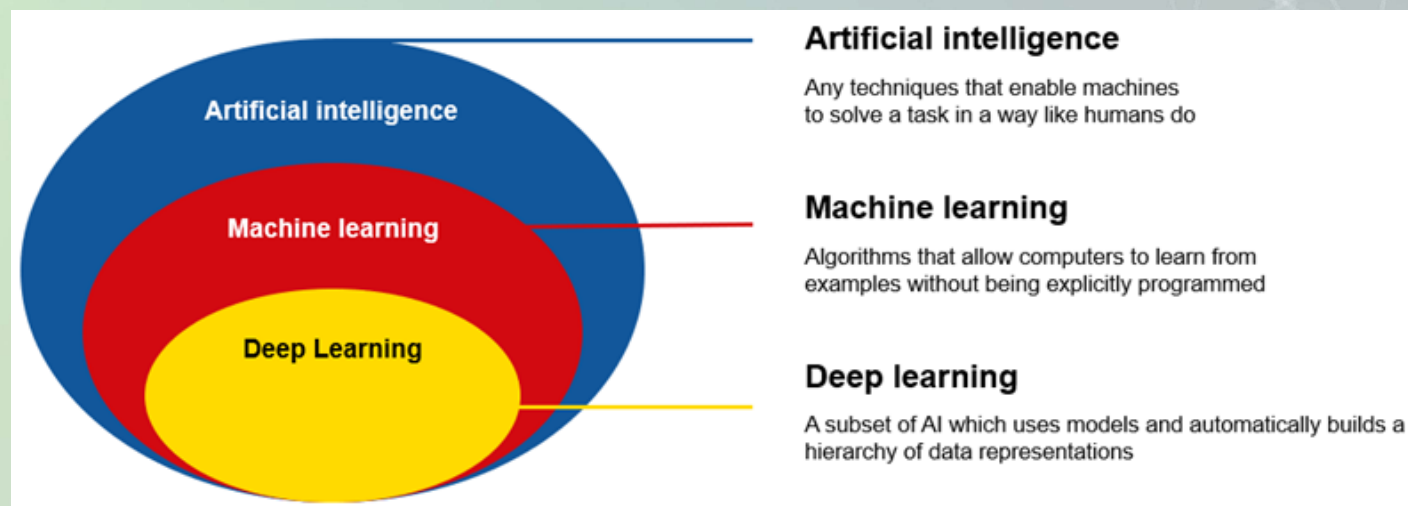
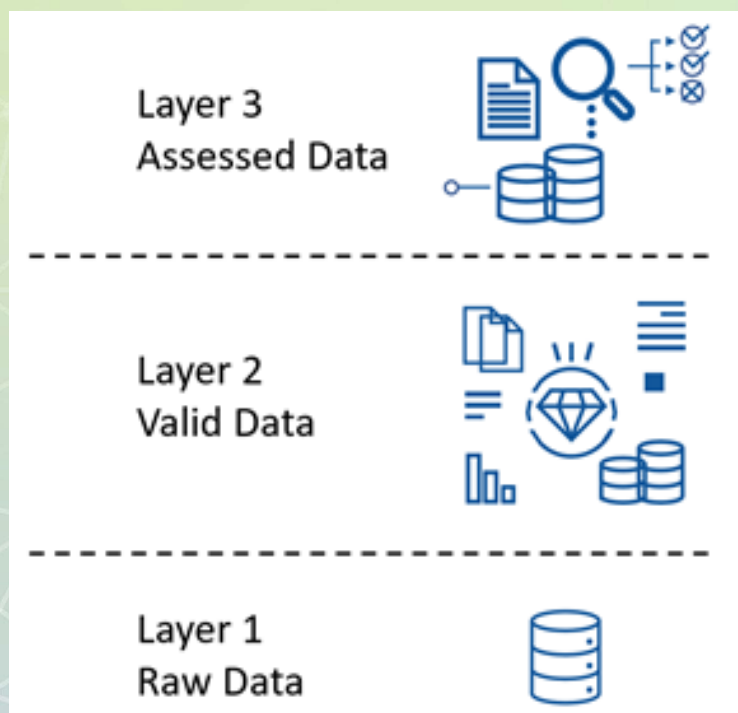




# Data and AI: it works... when set 😊

⇒ EDF and Omicron tried to somehow improve it...

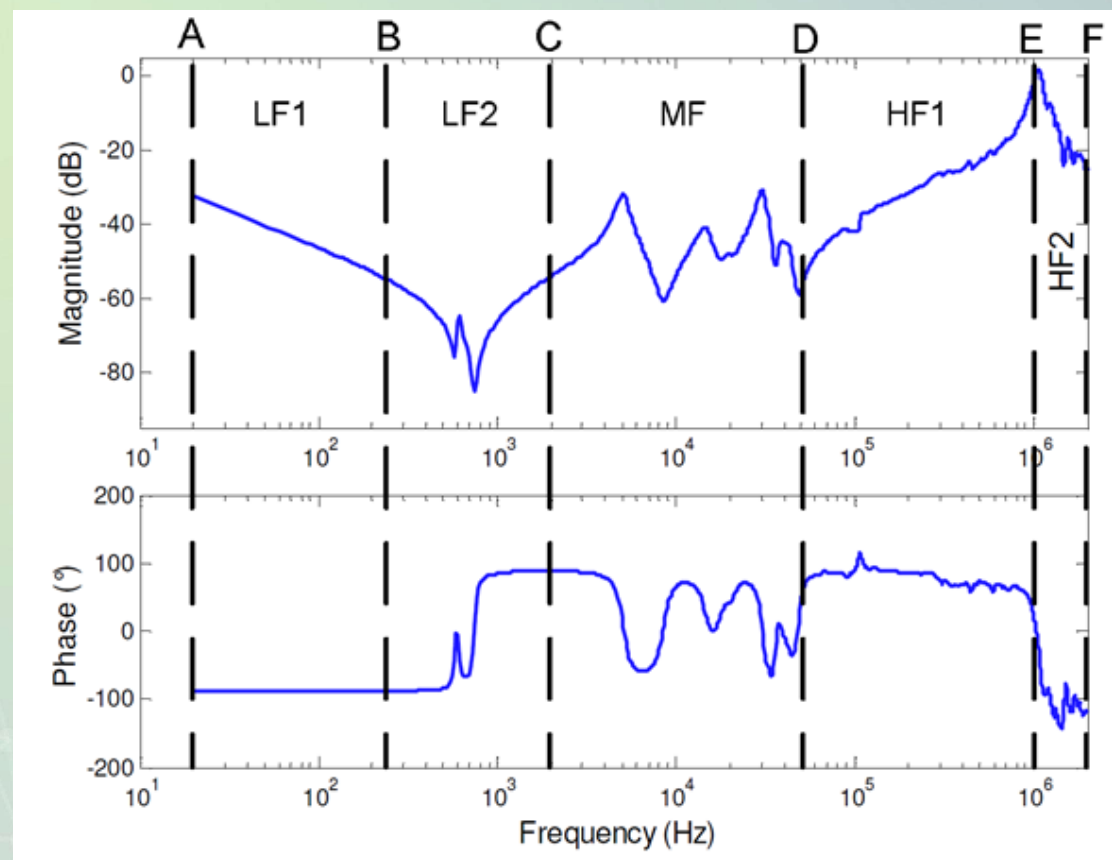
*Especially that FRA tests knowing winding design or confirmed problems are not that easy to find...*





# Nichols plots => try to automate pattern prediction

- > Nichols plot + histograms is a representation between amplitude and phase => not classic analysis.
- > Applied with histograms and on typical frequency sub bands (significant).

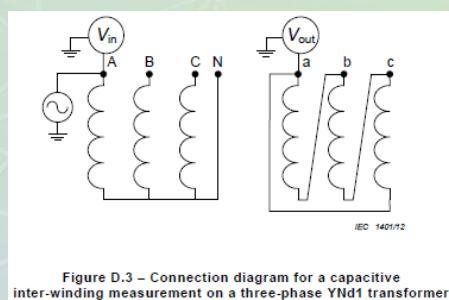
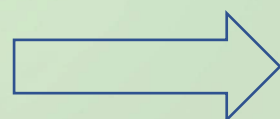
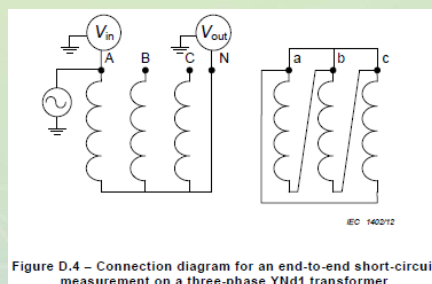
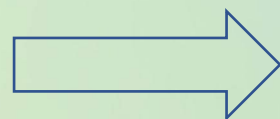
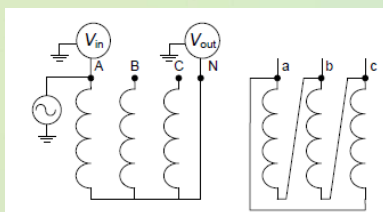


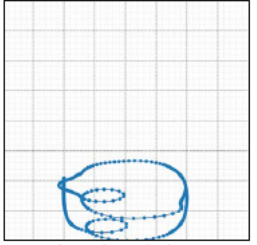
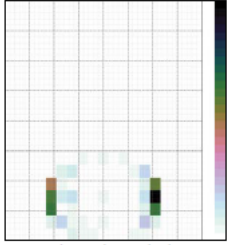
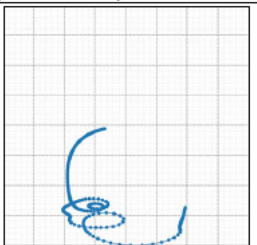
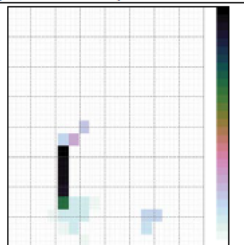
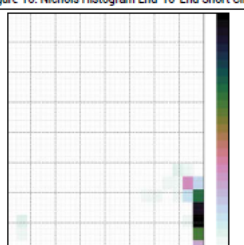




# Pattern prediction of measurement type

- On 20 Hz -> 30 kHz sub band + > 20 000 cases analyzed => 89% of recognition success 😊
  - Improve automatic analysis!



| Table 2. Comparison of SFRA measurement types (20–30 kHz) |                                                                                                                             |                                                                                                                                               |
|-----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Measurement type                                          | Nichols plot (scaled)                                                                                                       | Nichols plot histogram (scaled)                                                                                                               |
| End-to-End Open Circuit                                   | <br>Figure 13. End-To-End Open Circuit   | <br>Figure 14. End-To-End Open Circuit                     |
| End-to-End Short Circuit                                  | <br>Figure 15. End-To-End Short Circuit | <br>Figure 16. Nichols Histogram End-To-End Short Circuit |
| Capacitive Interwinding                                   | <br>Figure 17. Capacitive Interwinding | <br>Figure 18. Capacitive Interwinding                   |



# Pattern prediction of winding type

- On 30 kHz -> 600 kHz sub band + 17 cases analyzed => 85% of recognition success 😊
  - Improve automatic analysis!

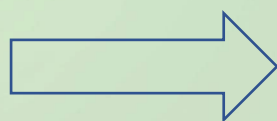
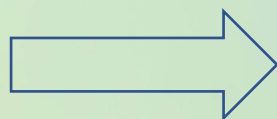
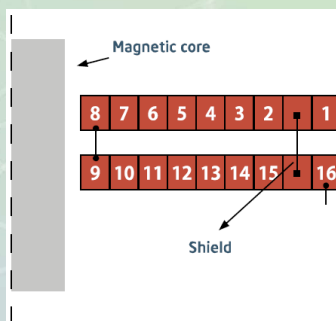
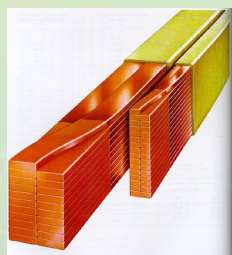
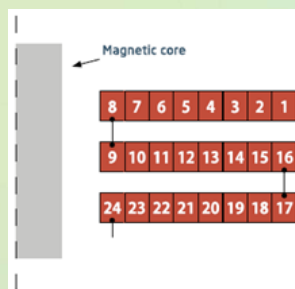
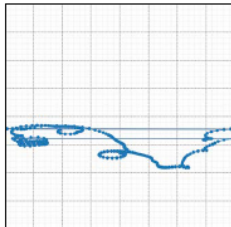
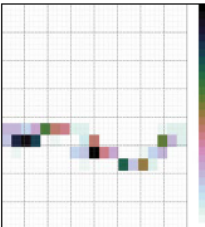
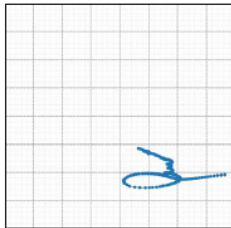
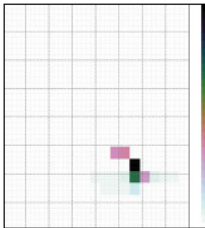
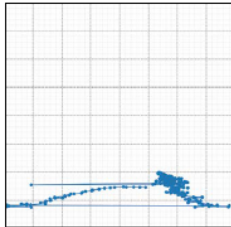
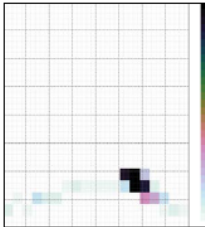


Table 3 Comparison of high and low voltage winding types (30–600 kHz)

| Winding type    | Nichols plot (scaled)                                                                                                                     | Nichols plot histogram (scaled)                                                                                                           |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Continuous (HV) | <br>Figure 22. Continuous Disk Winding (HV)            | <br>Figure 23. Continuous Disk Winding (HV)            |
| CTC (HV)        | <br>Figure 24. CTC Winding (HV)                       | <br>Figure 25. CTC Winding (HV)                       |
| Shielded (HV)   | <br>Figure 26. Shielded Continuous Disk Winding (HV) | <br>Figure 27. Shielded Continuous Disk Winding (HV) |







# Conclusions

- Nichols plot histogram + AI classification of FRA (windings, types of tests) can improve diagnosis 😊
- FRA automatic analysis with AI can help users and experts for a more efficient diagnosis.
- This FRA field is still under development 😊 let's continue!

