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Detection of winding faults with frequency response analysis (FRA)

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Detection of winding faults with frequency response analysis (FRA)



DETECTION OF WINDING FAULTS WITH FREQUENCY RESPONSE ANALYSIS (FRA)

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FRA – What is it?

- Reliable and sensitive Method to evaluate the mechanical and electrical integrity of transformers active part
- Measurement of the transfer function for every winding over a wide frequency range
- Comparison of current test results with reference data (historical fingerprints, sister units, phase to phase)

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Detection of winding faults with frequency response analysis (FRA)



What defects can be detected by FRA?



- ➔ Winding deformation axial & radial (buckling, tilting...)
- ➔ Axial displacement between HV- and LV windings
- ➔ Shorted or open turns
- ➔ Faulty grounding of core or screens
- ➔ Core movement or shorted laminations
- ➔ Problematic internal connections

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When we use FRA?



- ➔ Prove the transformer after short circuit testing
- ➔ Check the integrity of transformers after transportation
- ➔ Routine testing
- ➔ Condition assessment after the occurrence of high fault currents
- ➔ Diagnosis after transformer alarm or protection tripping

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When we use SFRA?



- ➔ Testing after significant changes of monitored values (e.g. combustible gases....)
- ➔ Further investigation after the observation of unusual routine test results
- ➔ Scientific investigations

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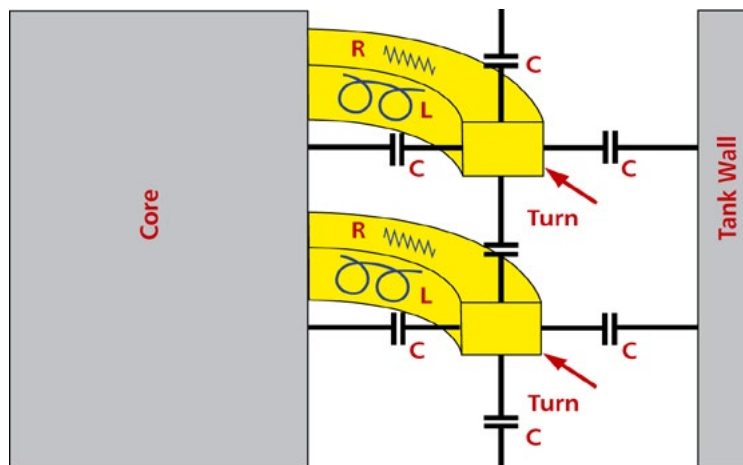
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Model of transformer winding

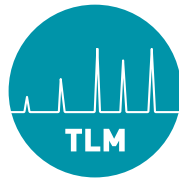


The transformer as a network



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What about the forces?



$$F \sim I^2$$

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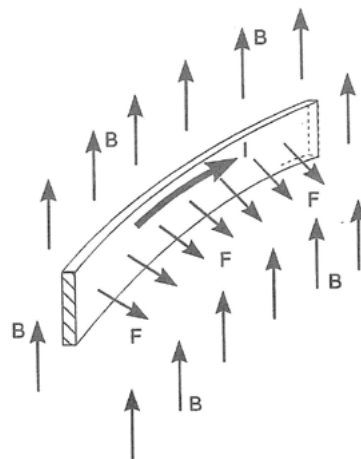
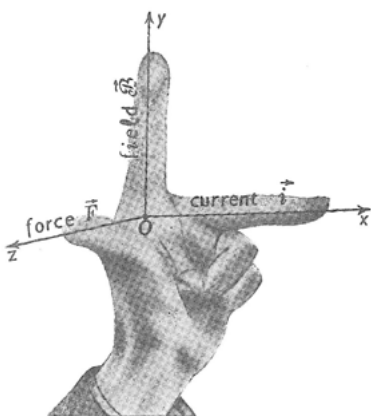
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Force direction



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a) **forced buckling** b) **free buckling**

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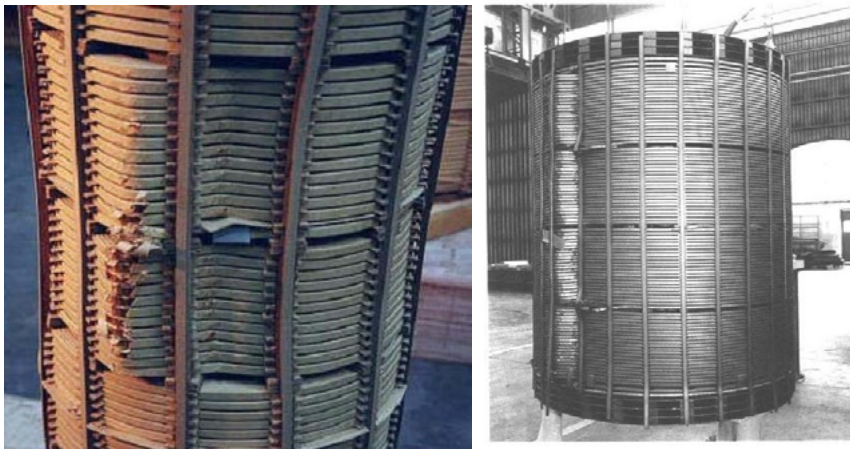
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Free and forced buckling



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Source: G. Bertagnolli, Short Circuit Duty of Power Transformers, ABB Trasformatori, Legnano

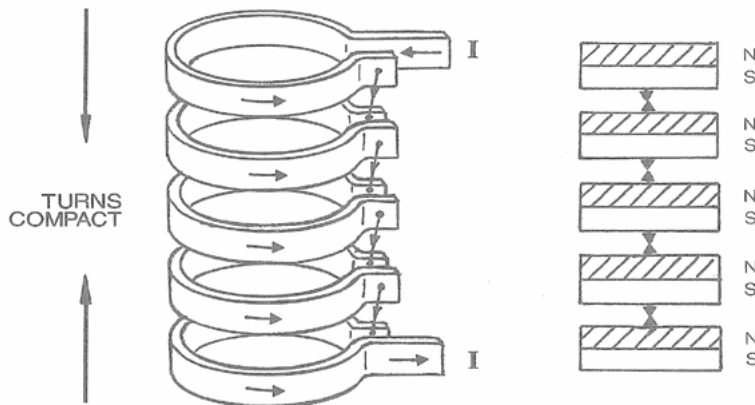
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Forces due to axial displaced windings



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Source: G. Bertagnolli, Short Circuit Duty of Power Transformers, ABB Trasformatori, Legnano

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Tilting due to axial compressive forces

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a) normal position

b) tilted conductors

Source: G. Bertagnolli, Short Circuit Duty of Power Transformers, ABB Trasformatori, Legnano

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Forces due to axial displaced windings

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Source: G. Bertagnolli, Short Circuit Duty of Power Transformers, ABB Trasformatori, Legnano

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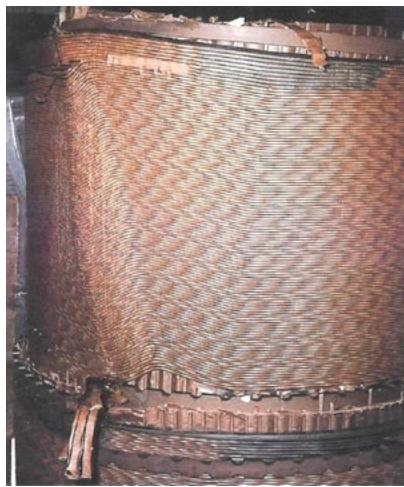
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Axial Collapse



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Source: G. Bertagnolli, Short Circuit Duty of Power Transformers, ABB Trasformatori, Legnano

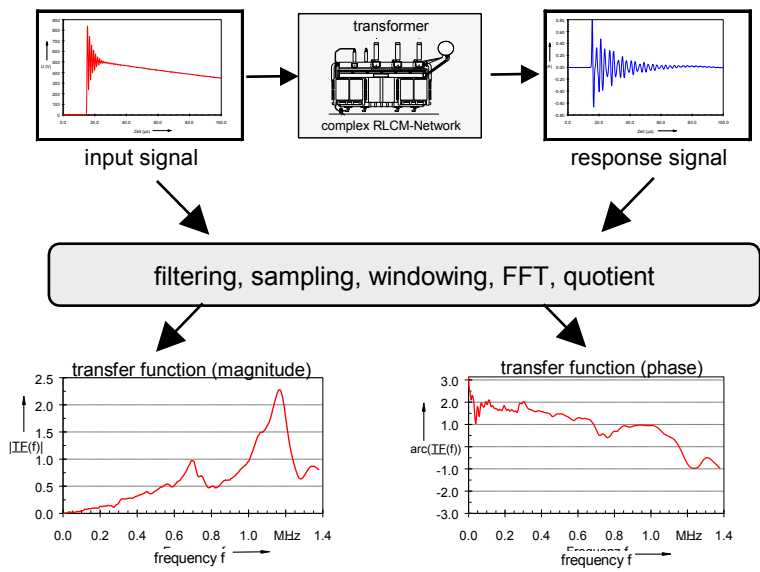
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FRA with impulses (IFRA)

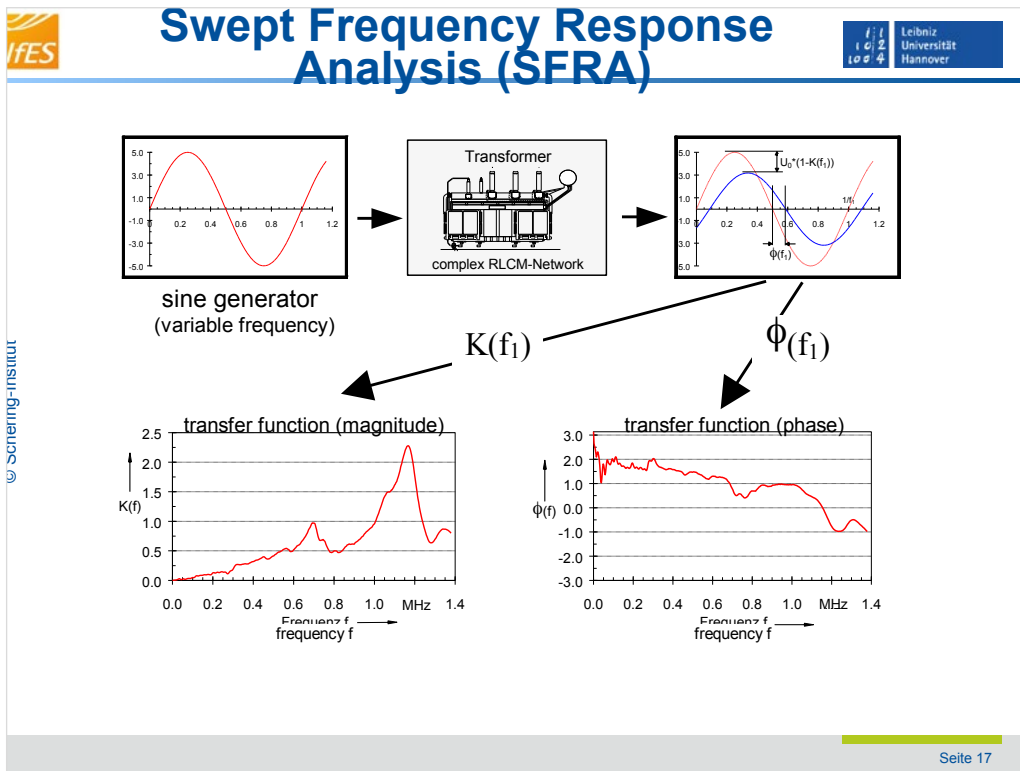


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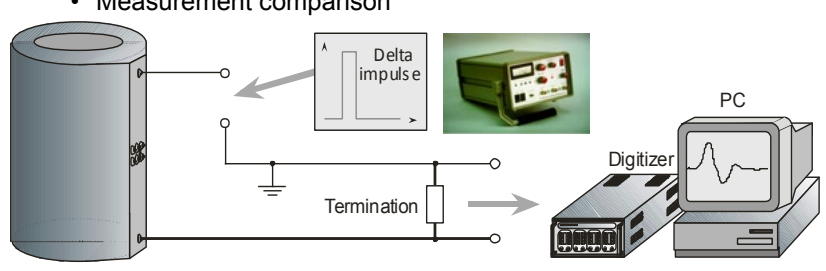
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FRA (Frequency Response Analysis)

- IRA (Impulse Response Analysis)
- SRA (Step Response Analysis)
- **FRA (Frequency Response Analysis)**
- System Response Measurement
 - Determination of short circuit in winding as well as winding deformation
 - Measurement comparison



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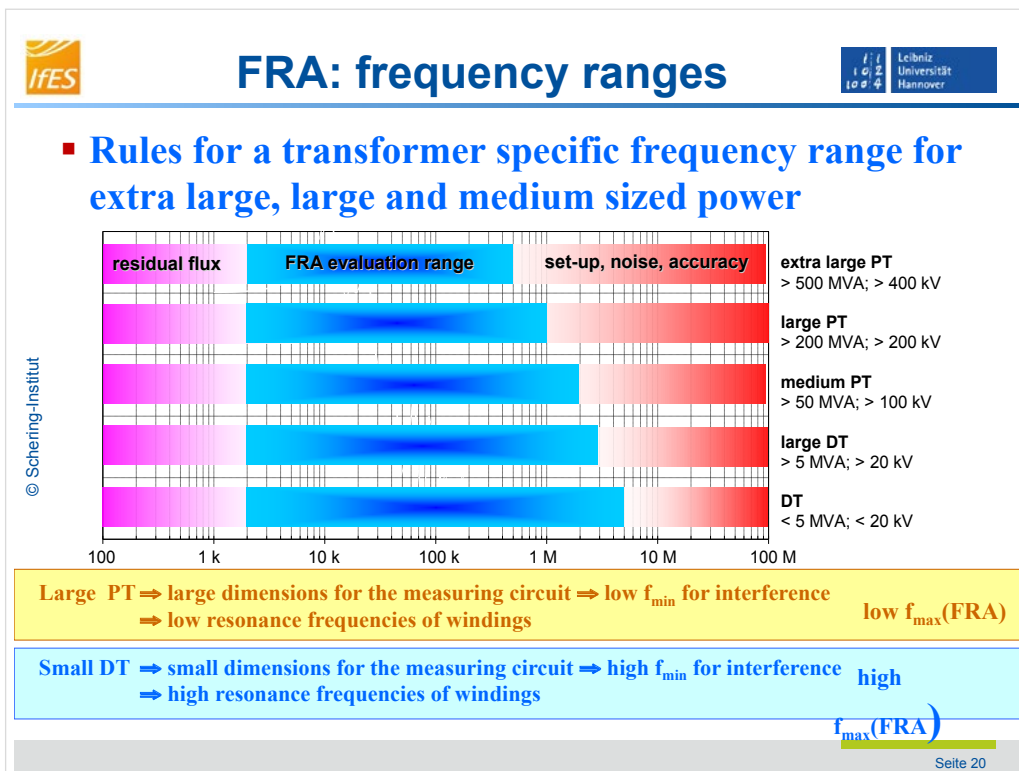
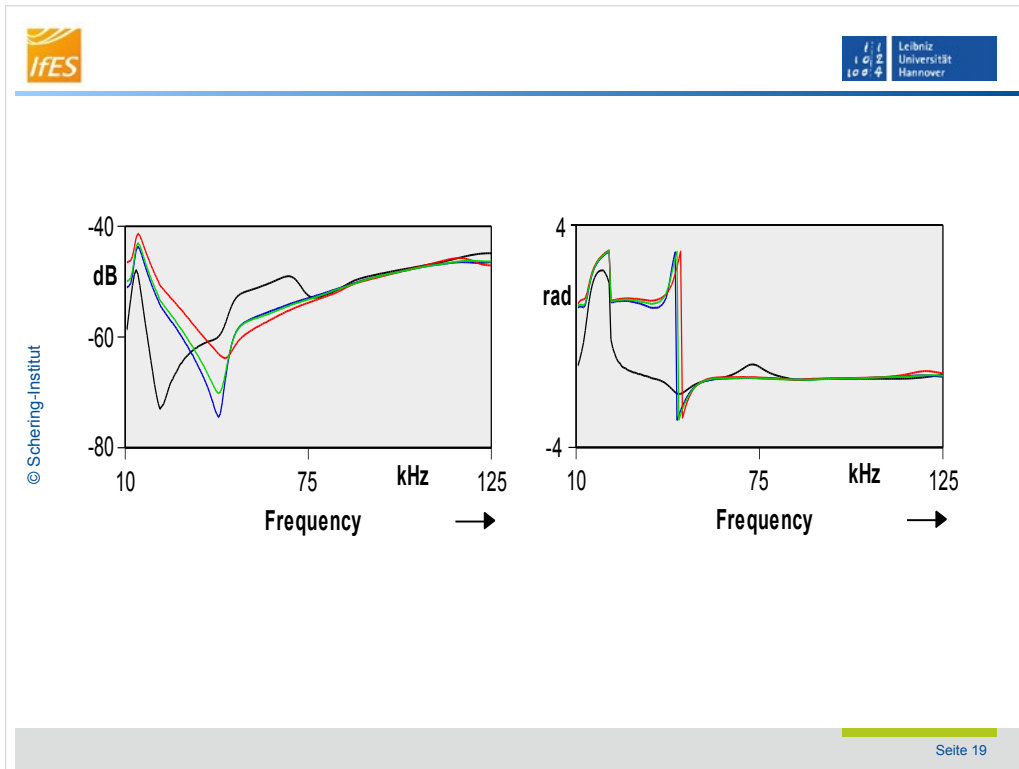
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Grounding concept of measurement cables

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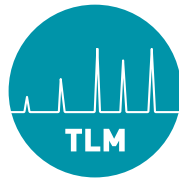
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Three case studies

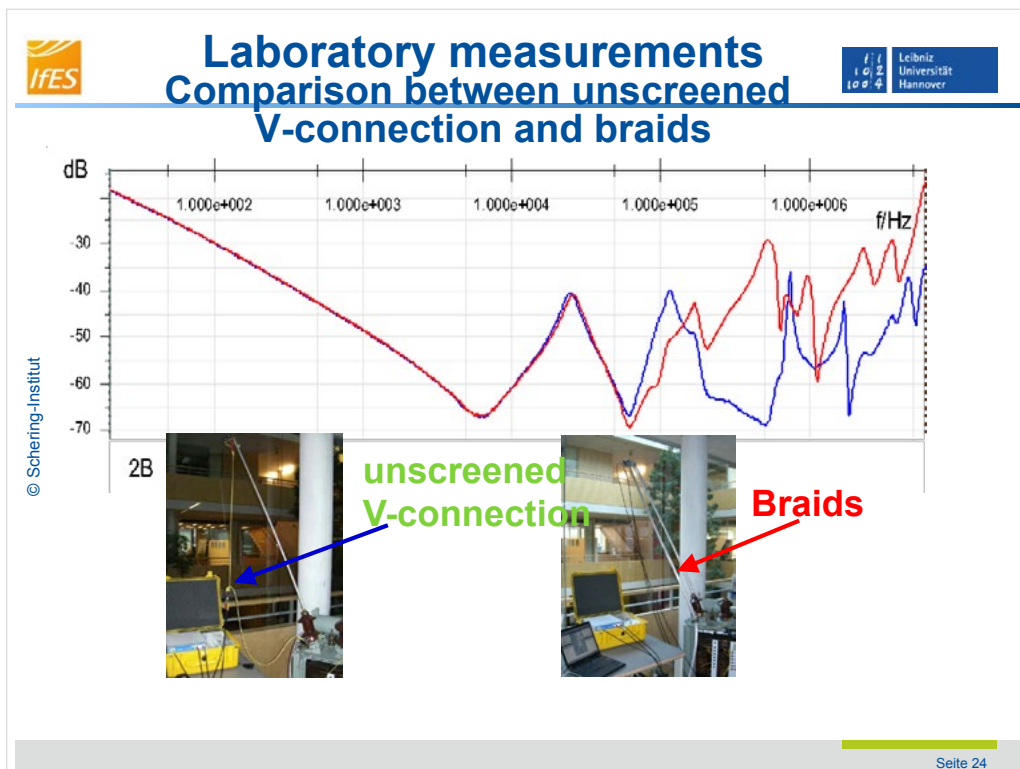
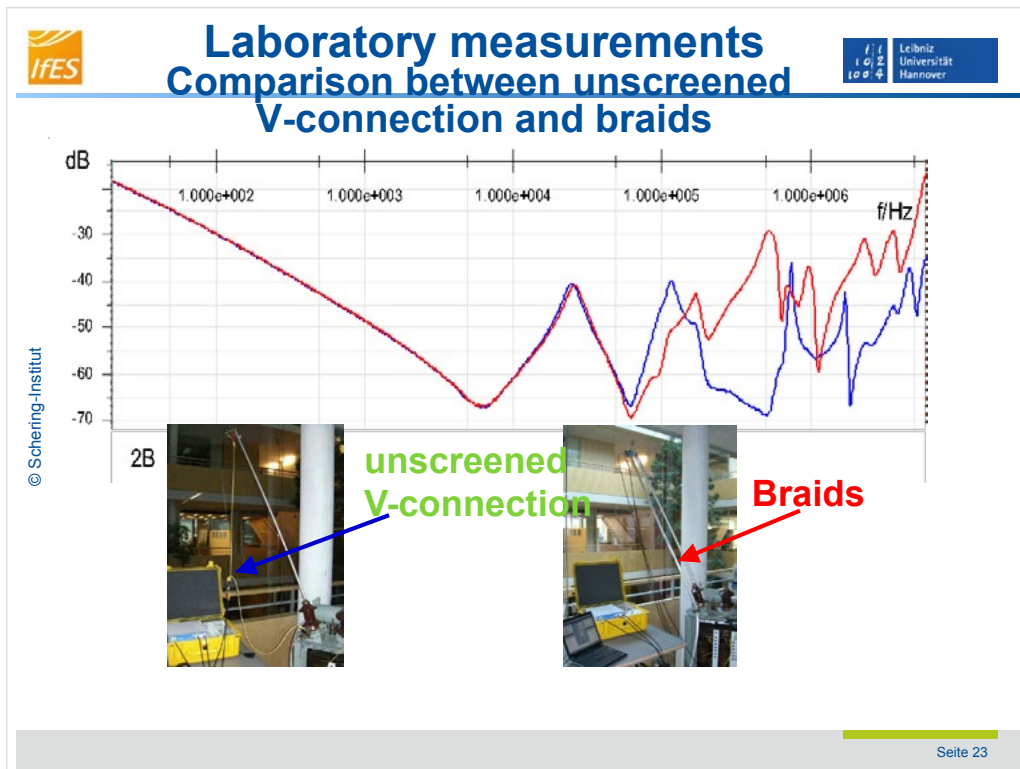
1. Comparison between wire, V-connection and braids
2. Comparison of the reproducibility
3. Measurement on a single phase 333MVA transformer in a substation

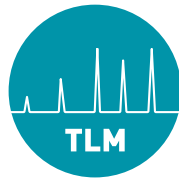
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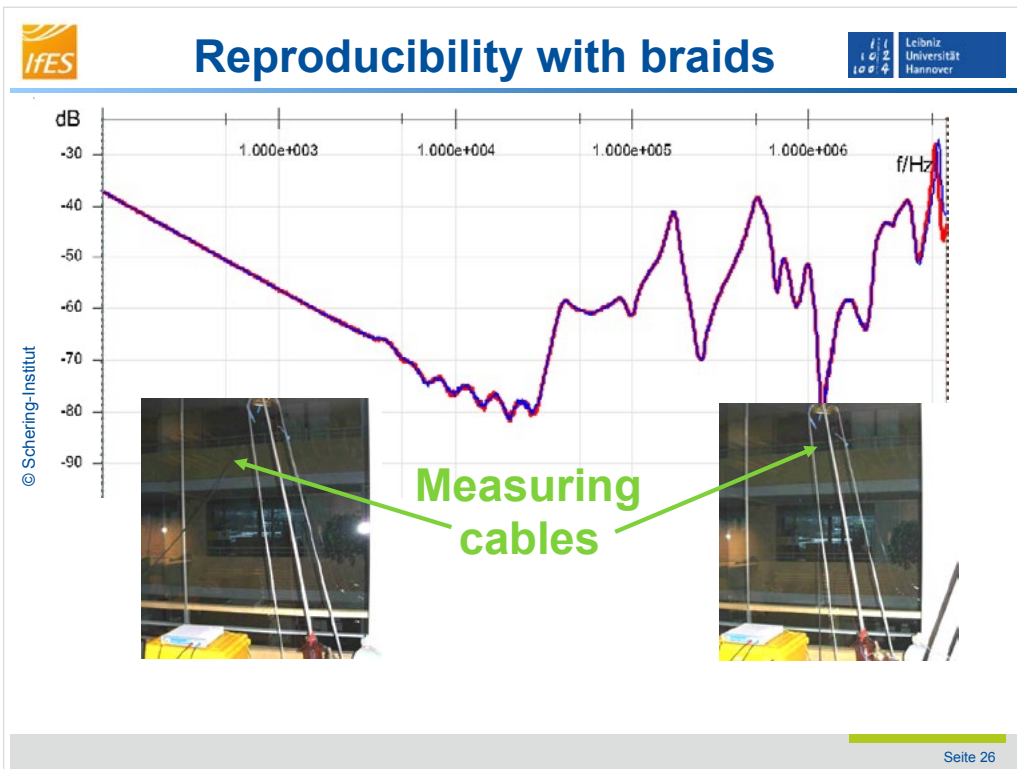
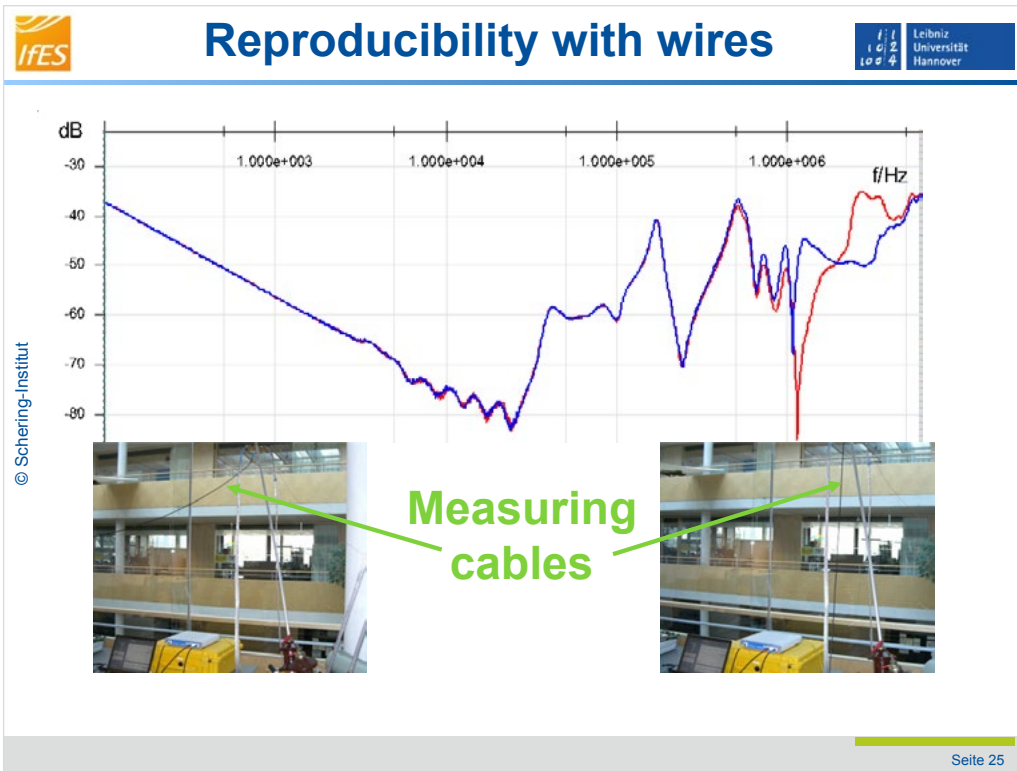


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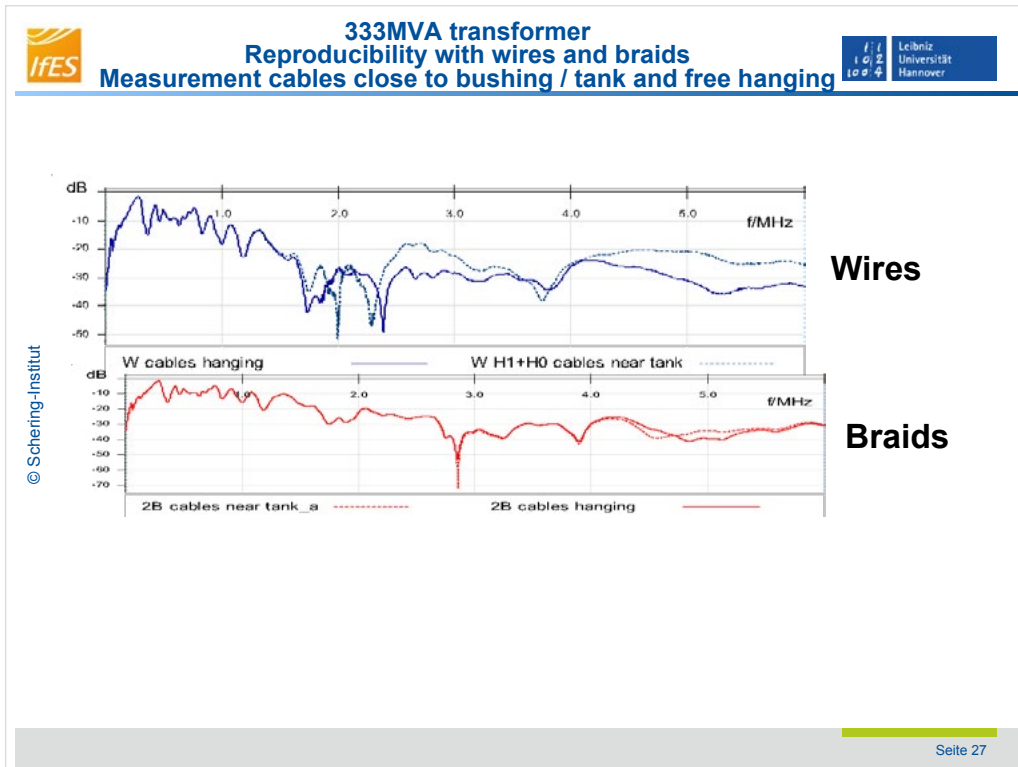


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Detection of winding faults with frequency response analysis (FRA)





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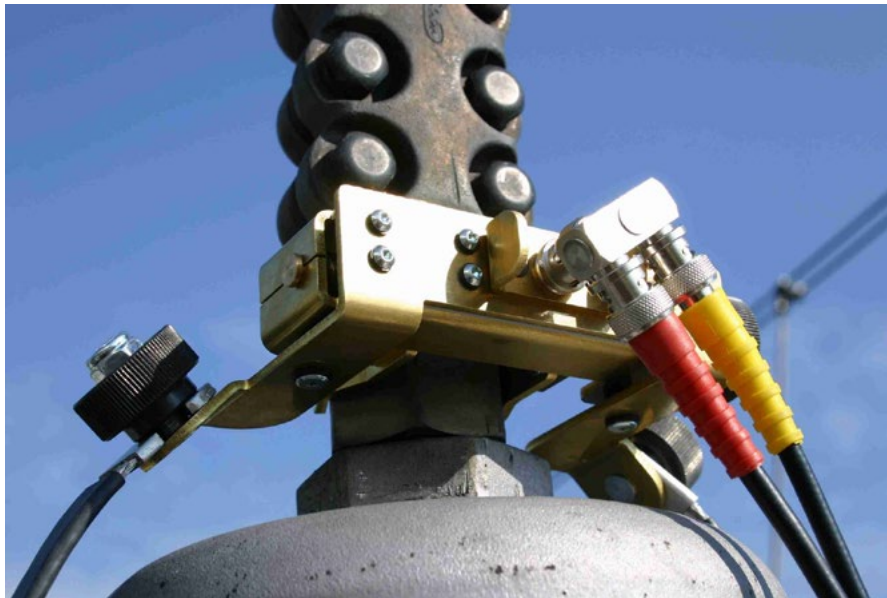
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Connection N terminal



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Connection clamp



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Connection flange

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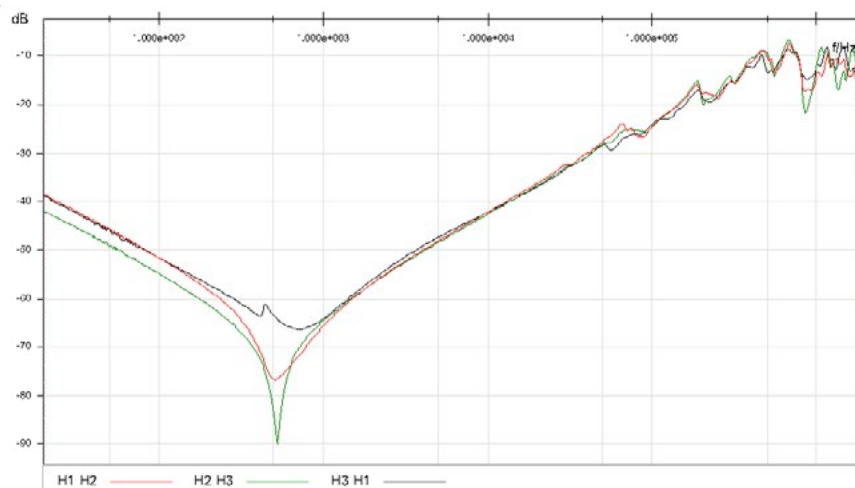
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Practical Case: Open delta winding after short circuit testing

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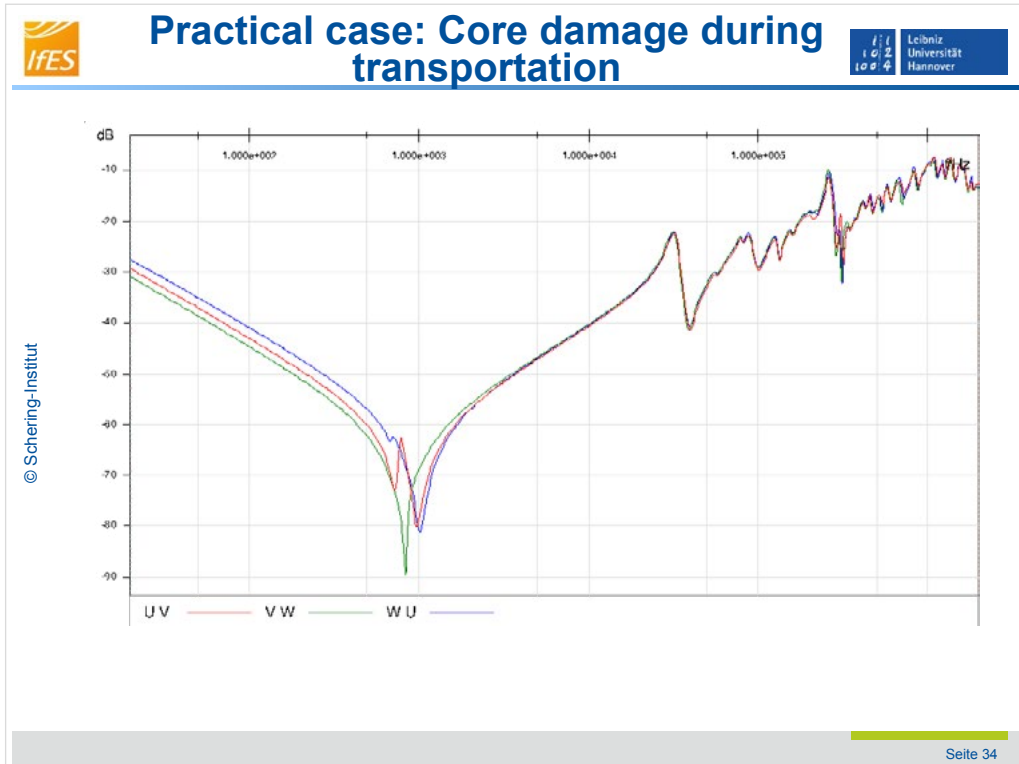
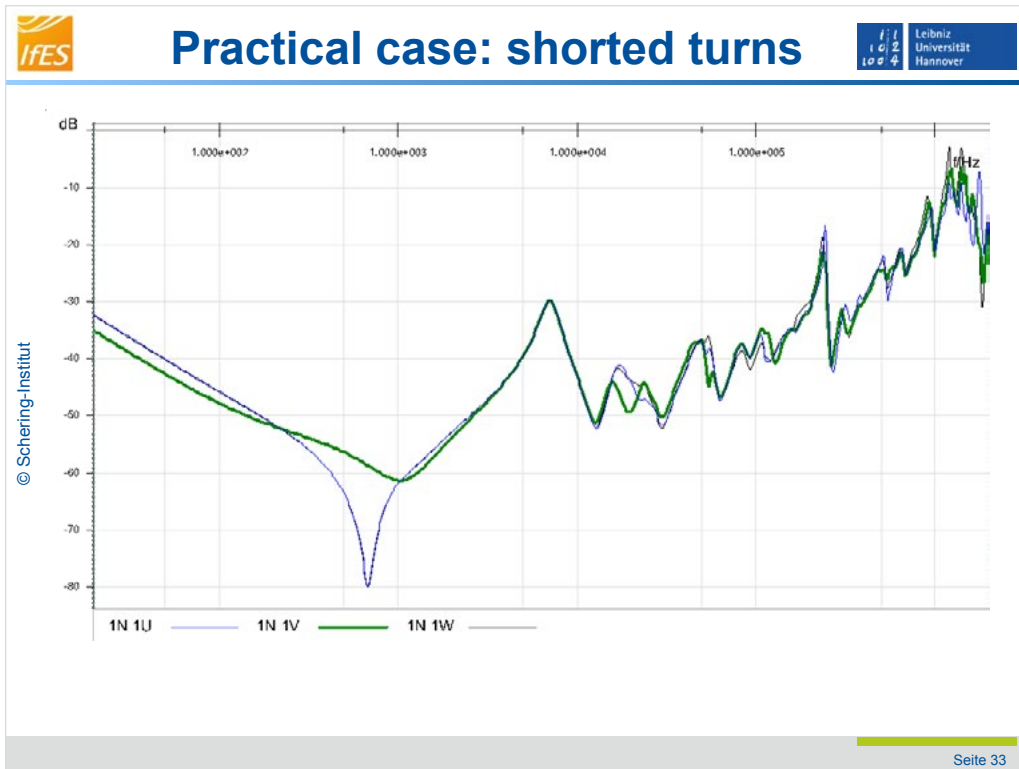
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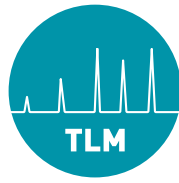


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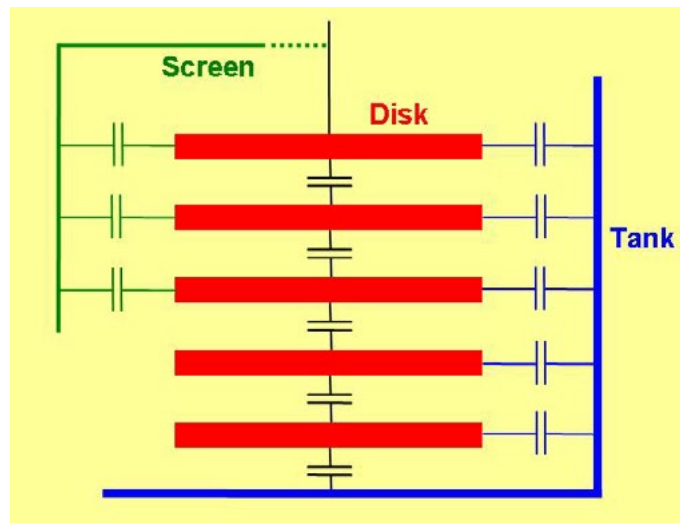
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Interrupted screen connection

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HV Screen

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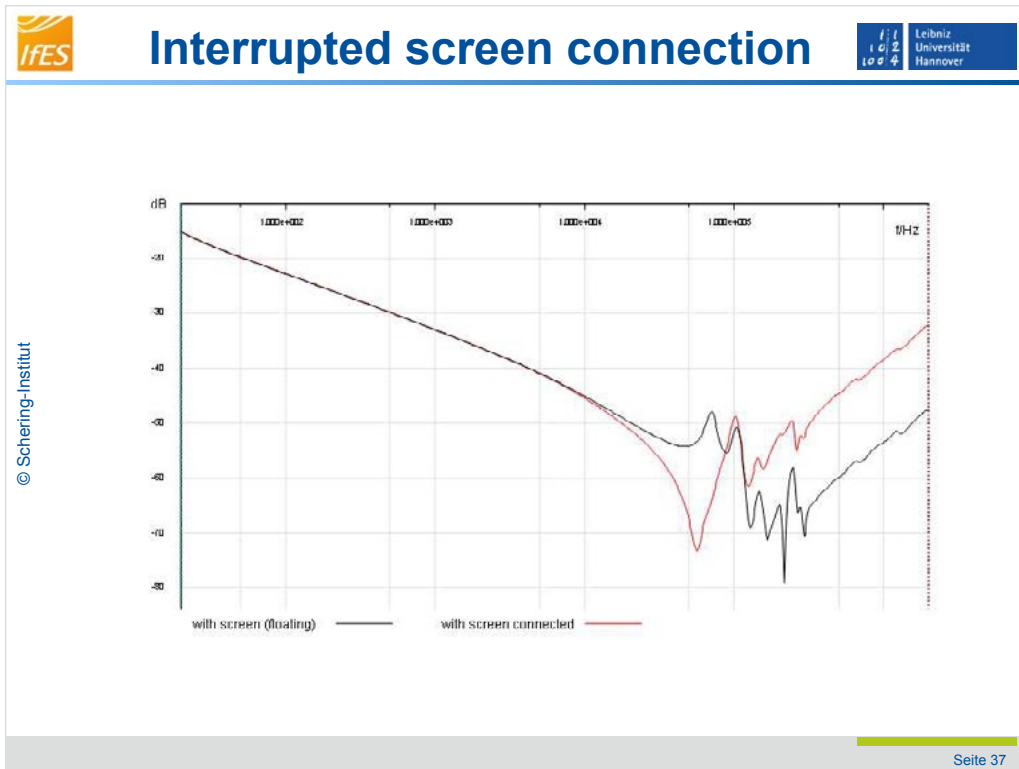
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- IFES** **Requirements regarding the connection technique** 
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- **Reliable electrical contact to the bushing terminal and the reference potential (usually the tank)**
 - **Ground extension of the coaxial leads of low inductance (broad braids with large surface, made of a large number of small wires to reduce the skin effect at higher frequencies)**
 - **Ground extension to the base of the bushing as short as possible**
 - **Smallest achievable loop of the earth connections to avoid noise interference**
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Conclusion



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- FRA-devices need a sufficient dynamic range (at least down to -90 dB).
- Impuls measurements are not able to "see" the lower frequency range, which is expressive for several types of failure.
- The connection technique is of outstanding importance for true valuable test results!

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Conclusion



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- **The SFRA is a powerful method to evaluate the mechanical and electrical integrity of transformers active part**
- **The reproducibility, absolutely necessary for a comparative method, is certainly achievable with modern test equipment**
- **Highest accurateness is essential when establishing the connections**
- **FRA-Fingerprints are an usefull and valuable investment which can get with small effort**

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Motivation



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Don't let something like this happen to YOUR transformers!

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Good transport by ship



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Good transport by aircraft



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Not so good transport



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