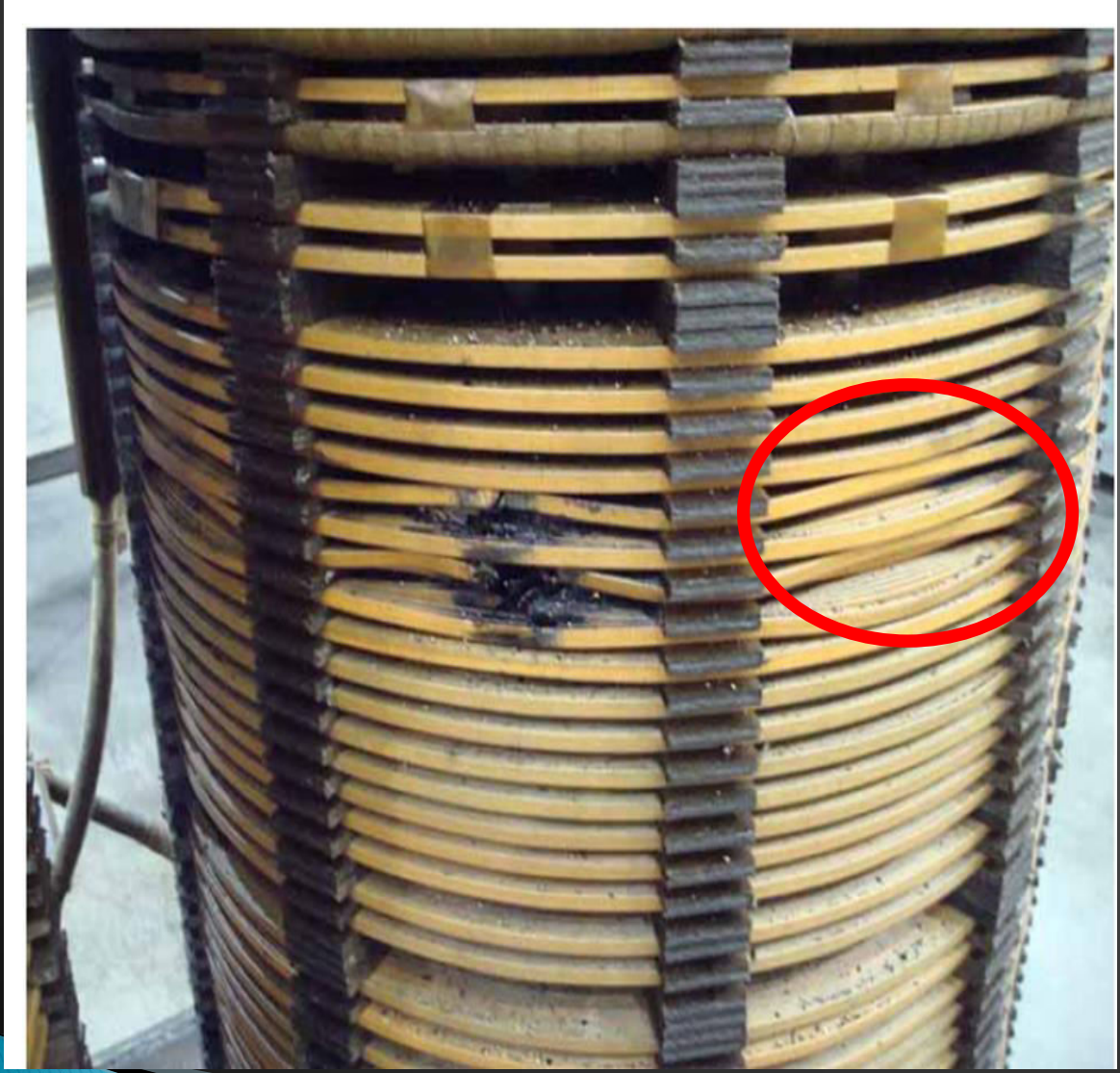
A Novel Generalized Analytical Framework to Diagnose True Radial and Axial Displacements in an Actual Transformer Winding

Pritam Mukherjee and L. Satish

HV Lab, Dept. of Electrical Engineering
Indian Institute of Science, Bangalore

Typical failures : Nascent stage



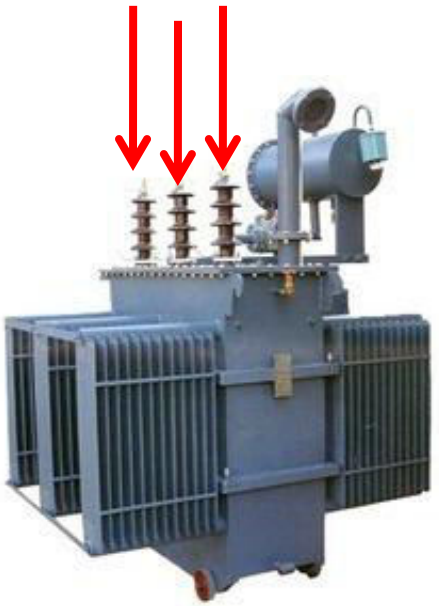
If the damage in the nascent stage is allowed to grow, it may develop into a catastrophic failure in future.

Thus, early detection of mechanical damage condition is paramount.

Objectives

1. Damage-condition be identified at its infancy
2. Its location and severity should be assessable
3. Accomplish the above task non-invasively, i.e., using ONLY quantities that are measurable from the terminals

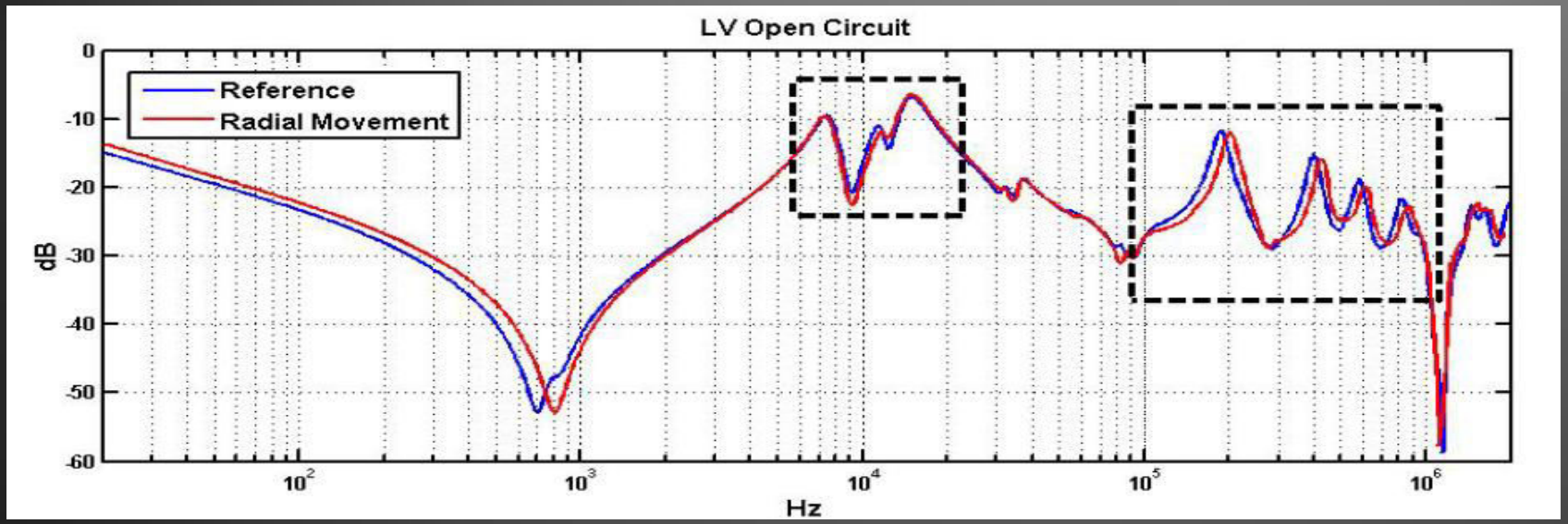
Terminals accessible

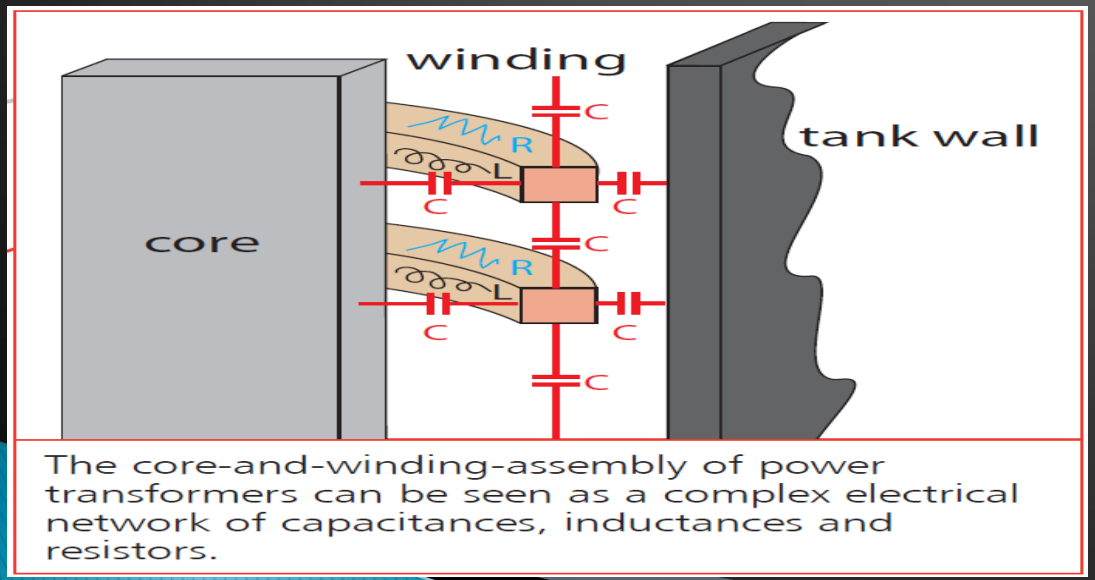


Answer: FRA

1. Provides prerequisite sensitivity to detect such conditions
2. A mismatch in FRA implies a damage-situation
3. But, currently is limited to detection only
4. Unique interpretation of FRA is not yet possible

FRA : Working principle

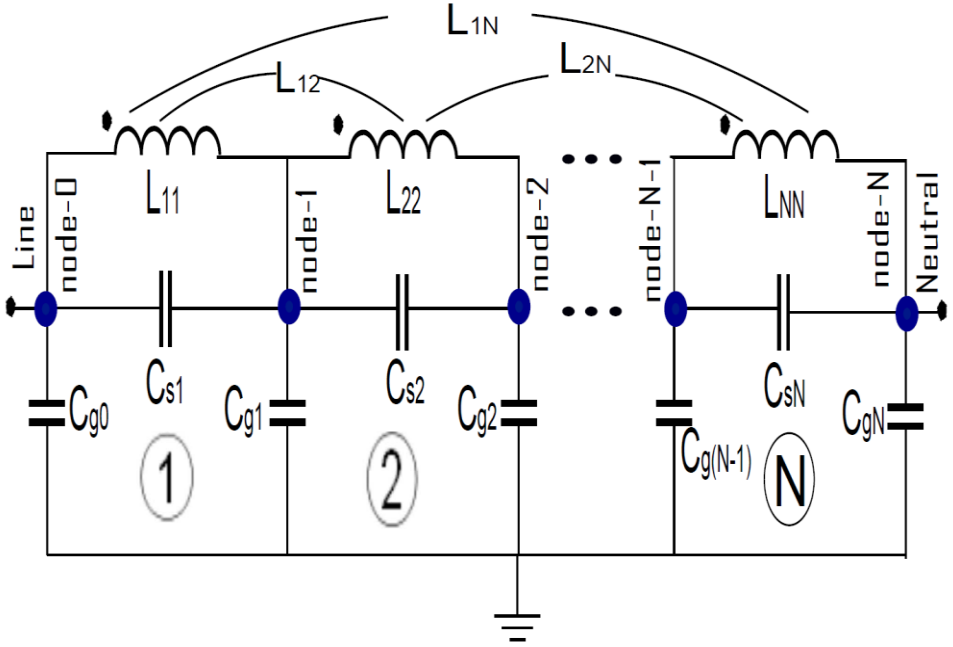


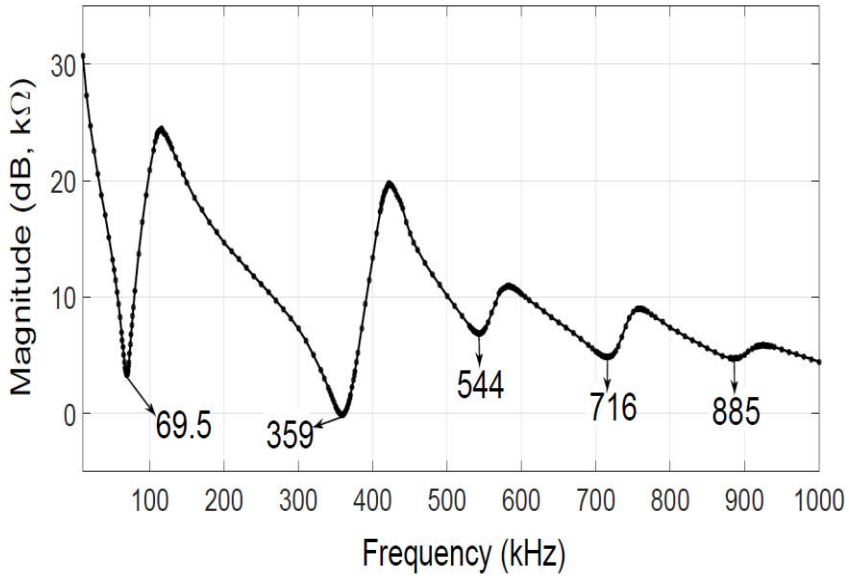


The core-and-winding-assembly of power transformers can be seen as a complex electrical network of capacitances, inductances and resistors.

A mechanical damage in the winding leads to inductance & capacitance changes. This causes a new set of natural frequencies.

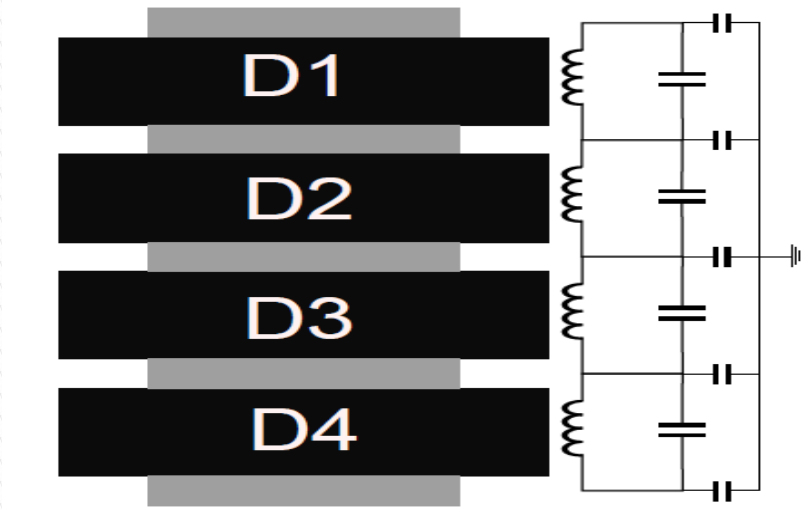
Analytical correlation linking natural frequency and winding parameters

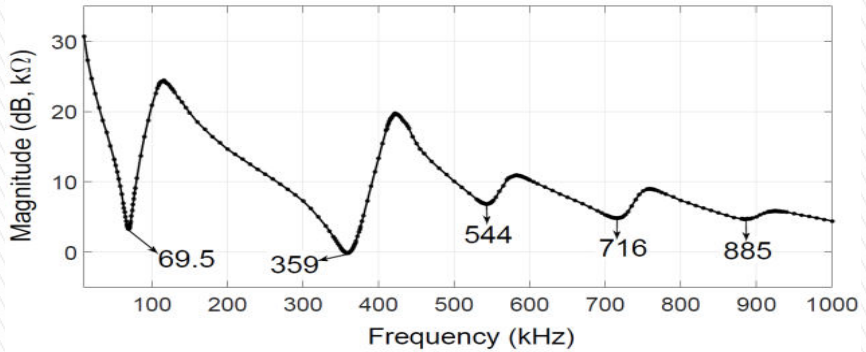




$$\sum_{i=1}^{N} \frac{1}{\omega_{sc_i}^2} = \sum_{i=1}^{N} L_{ii} C_{si} + \sum_{i=1}^{N} \mathbf{M}_{0i} C_{g\,i}$$

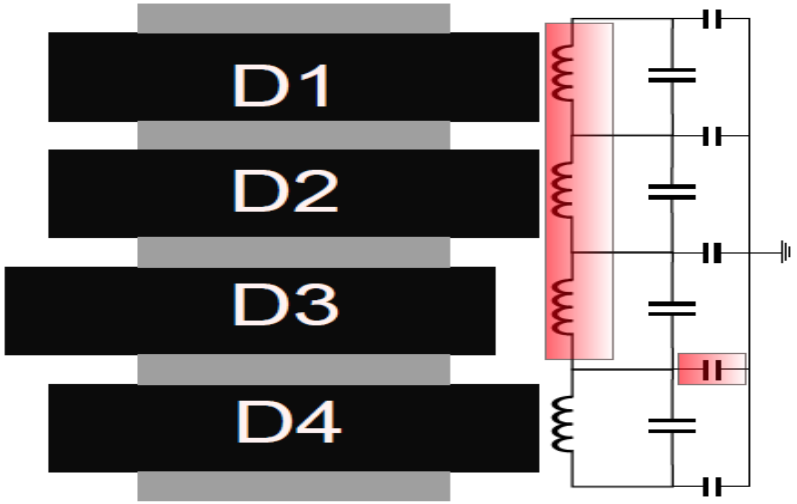
Radial Displacement Localization

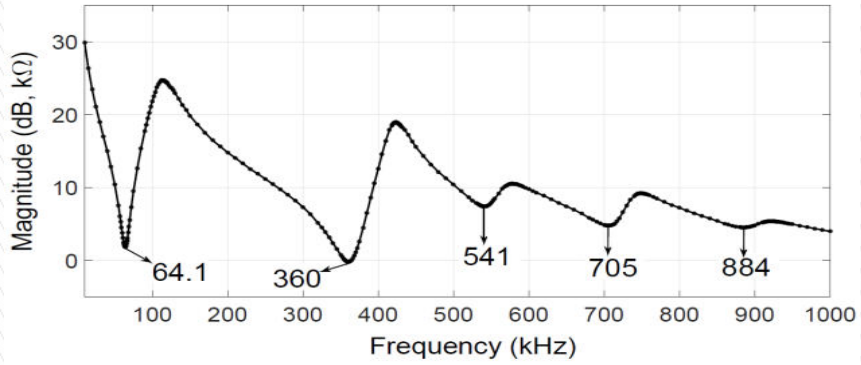




(a) DPI of nominal winding

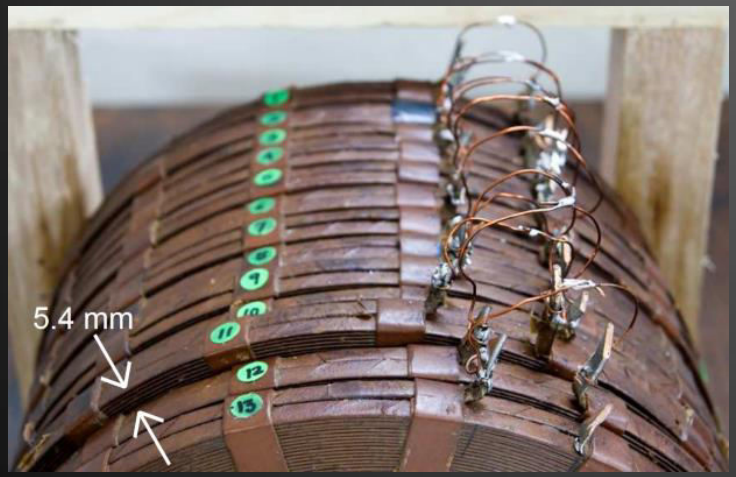
$$\Delta\Psi_{scnf} = \sum 1/\hat{\omega}_{sc_i}^2 - \sum 1/\omega_{sc_i}^2 = \mathbf{M}_{03}\Delta C_g$$





(b) DPI of winding after 11th is disk-pair radially displaced

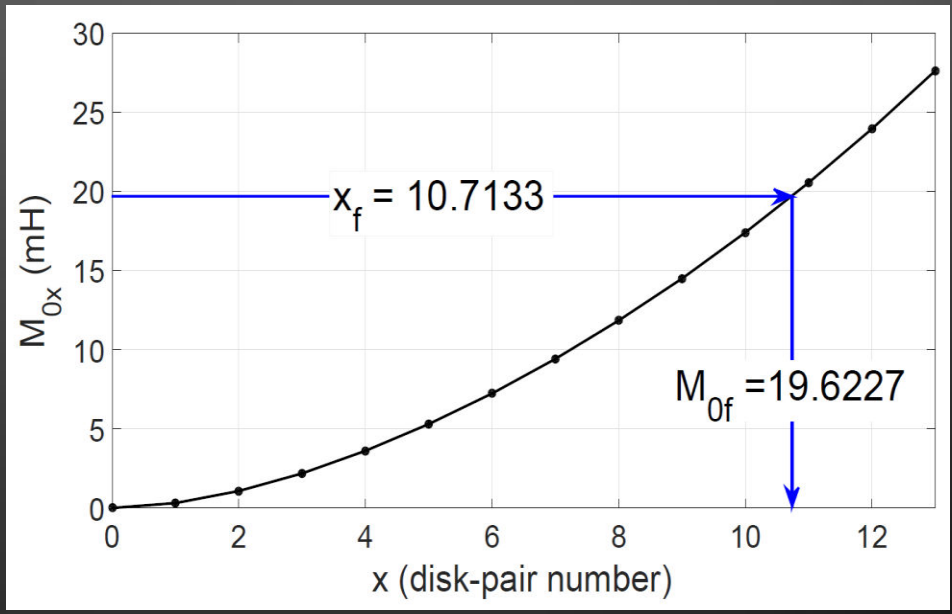
Result: RD location



$$\Delta\Psi_{scnf} = \hat{\Psi}_{scnf} - \Psi_{scnf}$$
$$= 6.5302 - 5.6080 = 0.9223$$

$$\Delta C_g = \hat{C}_G - C_G = 0.047\ nF$$

$$\mathbf{M}_{0f} = \Delta\Psi_{scnf} / \Delta C_g = 19.6227\ mH$$

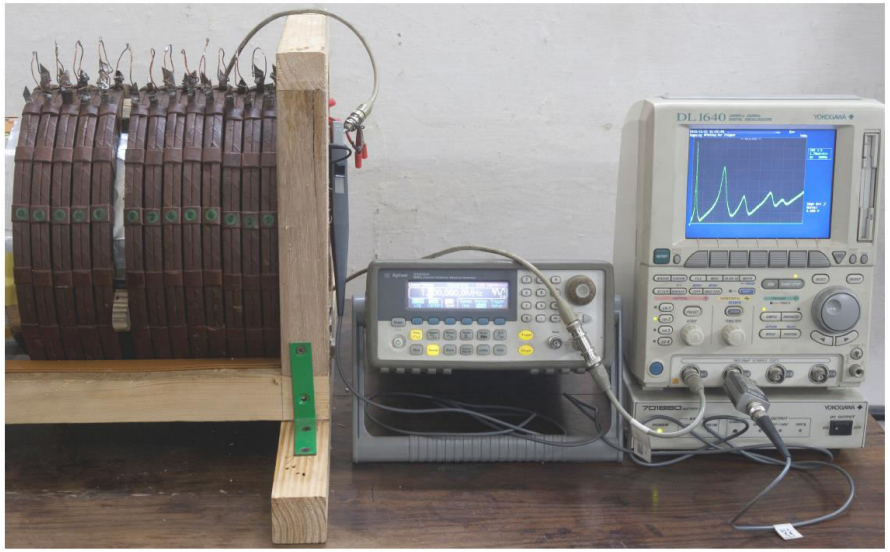


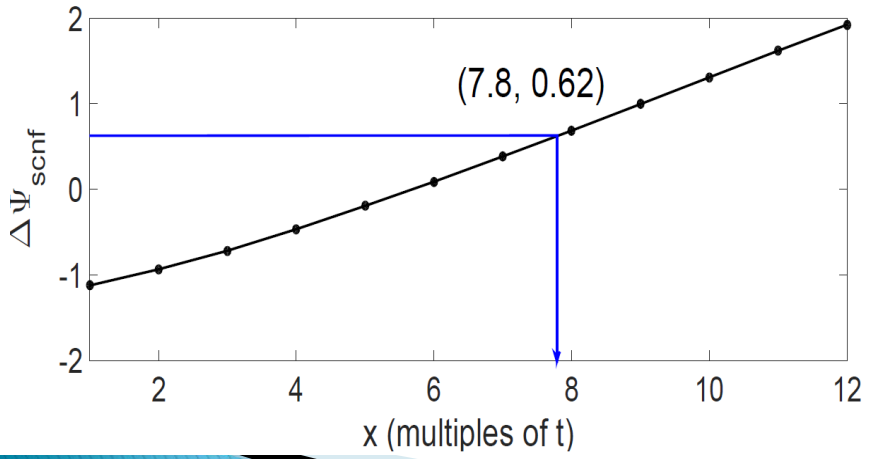
RD: Assessment of Severity

PROPORTIONALITY OF $\Delta\Psi_{scnf}$ W.R.T. SEVERITY

Disk pair	extent (mm)	SCNFs (kHz) 1st	2nd	3rd	4th	5th	$\Delta\Psi_{scnf}$
4	3	69.1	354	536	718	886	0.0687
4	4	68.8	348	531	718	888	0.1236
4	5	68.5	345	529	718	886	0.1751
7	3	68.6	354	548	714	889	0.1428
7	4	67.6	346	547	710	888	0.3137
7	5	67.2	345	548	707	888	0.3812
10	3	68	362	541	715	889	0.2315
10	4	66.7	361	536	714	889	0.4499
10	5	65.7	361	535	713	888	0.6251
10	6	63.7	359	533	712	886	1.0025

Axial Displacement





The monotonic variation of $\Delta\Psi_{scnf}$ is the key to localize the change. This property is used for locating and assessing the severity of an RD

An AD involves a large number of inductance changes as well as capacitance changes. So, handling AD is more involved. But, monotonicity of $\Delta\Psi_{scnf}$ can be used to advantage for the task of localization

AD: varying degree

Performance of the algorithm independent of the location or the extent of AD

Table 4.5: CASE-B: RESULTS FOR AD WITH VARYING EXTENT OF DISPLACEMENT

Disk pair	Extent of AD (cm)	SCNFs (kHz) 1st	2nd	3rd	4th	5th	ΔC_g (nF)	ΔL_{eq} (mH)	Location	Estimated extent (cm)
4-5	0.6	42.3	283	482	694	862	0.047	-0.55	5.7 ⇒ D5-D6	$0.3089t$=0.52
	1.4	42.4	278	473	700	845	0.075	-1.03	5.9 ⇒ D5-D6	$0.599t$=1.01
	2.0	42.4	275	470	695	842	0.087	-1.68	5.8 ⇒ D5-D6	$1.026t$=1.74
9-10	0.6	42.0	287	477	684	870	0.038	-0.59	8.5 ⇒ D8-D9	$0.3323t$=0.56
	1.4	41.5	289	461	681	870	0.058	-1.13	9.1 ⇒ D9-D10	$0.7313t$=1.24
	2.0	41.1	288	455	678	870	0.092	-1.78	8.5 ⇒ D8-D9	$1.0954t$=1.85

Conclusions

- Analytical framework established for FRA diagnosis
- New relationships derived to correlate winding parameters to natural frequencies
- RD and AD in an actual winding can be located, its severities can also be assessed
- Future scope: Existing formulation has to be extended for diagnosis of other types of damages

Thank you

for your kind attention

Questions?