Detecting and Controlling Tank Resonance of Oil Immersed Power Transformers

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Abstract

In oil immersed power transformers, tank resonance can add a significant contribution to the generated noise. In the current study, we present a systematic procedure to first detect the resonance in the tank and then controlling its effect on noise. This is done by either shifting resonance frequencies or damping the resulting vibrations via optimizing additional outer stiffeners. The procedure consists of measurement, simulation and modelling.

The study shows the ability to predict the natural frequencies of the tank with a high accuracy, which is validated by applying hummer-test in specific places on the tank walls. Noise measurements are conducted before and after applying the outer stiffeners on the transformer walls with and without radiators. Results show that by following the presented procedure for a case study transformer it is possible to reduce the noise by about 5 dB.

Introduction

The transformer tank is mechanically, acoustically and electromagnetically connected to the active-part. Measuring the vibration on the tank walls, can delivers a useful information of the internal structure. The correlation between the vibrations on the active-part and on the tank are largely dependent on the characteristics of the transmission path between them.

In transformers design, there are different means for mechanical decoupling of the tank from the active-part have been adopted. For instance, using of corks and elastomers in the connection regions. In most power transformers, the windings and core are only connected to the tank via the bottom plate only, and hence, the direct mechanical vibration transmission to the tank are assumed to be minimized. Additional path for the mechanical transmission in the oil-immersed power transformers exists, which is through the oil, and so called the fluid-structure interaction (FSI). However, due to the damping and mass loading effects of the oil, the high frequency vibration on the tank reduces [1].

Using of the tank vibrations for monitoring the operational condition and detecting of the internal failure has been still one of the effective methods in the monitoring systems [2-3]

A model for monitoring the winding deformation by estimating the transfer to tank vibration and correlating them to the measured ones was presented and experimentally tested on a test transformer fitted with internal and external accelerometers, [4].
The acoustic pressure generated by vibration of the core and the windings transmits to tank surfaces through the oil medium. However, the acoustical damping and impedance factor of oil can impose an effect on the acoustical waves. The acoustical transfer factor always exists and there are few techniques to minimize its effect due to internal design restrictions (cooling, space, weight… etc.). When windings are loaded, the stray flux will generate. The leakage flux towards to the tank will impose a virtual magnetic force, which is responsible for the tank mechanical vibration.

The current study aims in presenting a complete procedure for first, detecting the tank resonance by means of sound measurements and hummer-impulse. Then, performing FEM simulation to match the calculated resonances with the measured ones. Finally, applying suitable controlling proposals supported by FEM simulations to minimize the effect of resonance and/or eliminate their effect by shifting them from the operating power frequency.

Approach

During the short-circuit noise test, there are many possible positions for resonance which lead to exceeding the guaranteed sound level. The resonance can occur in the active-part, which is mainly the winding, core and the clamping structure. However, detecting the active-part resonance is difficult to by measurements for the oil immersed power transformers.

Due to mechanical, electromagnetic and acoustical coupling between the tank and the active-part, the tank resonance are most probable to occur and can apply a significant effect on the generated noise.

The presented approach to detect the tank resonance and control its effect is depicted in figure (1). This approach is applied on a case study power transformer.

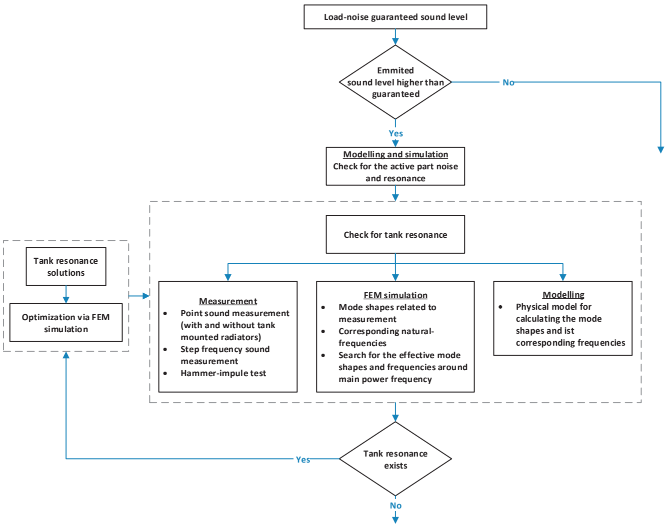

Fig 1: systematic working flow-chart

Noise measurements

Scan point measurement around the tank gives the information of the tank local resonance. For the radiator mounted tank type, if the tank resonance occurs, the radiators can add a significant increase to the generated noise. Removing the radiators, will give another indication for the tank resonance.

The proposed measuring procedure is done by performing sound level scan points (at 1/3 and 2/3 height) and walk-around scan measurements for the unit with radiators, while mounting the unit on a references pallet. Then repeating the measurement procedure for the unit without radiators, while mounting the unit on the same references pallet

Comparing the two measurements, figure (2) shows that without radiators the HV side emits less noise, whereas the conservator side emits higher noise. An indication of local resonance can be concluded in the HV side from the high deviation in the noise measurements and the reduction in noise when removing the radiators.

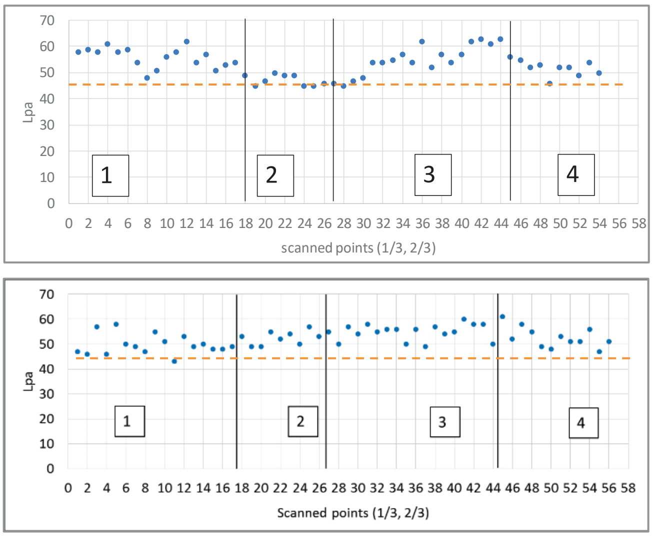

Fig 2: Scanned points sound pressure level measurements in dB(A) (1: HV, 2: conservator, 3: LV, 4: front)

To get more evidences of resonance occurrence. A frequency step measurements 40, 50, 60 Hz is done. By default, the higher the frequency the higher the noise. In figure (3) the frequency analysis in 1/3 octave band form shows that the main band of 60 Hz (center freq. of 125 Hz) is lower than that of the 50 Hz (center freq. of 99 Hz). Additional, the main band of 50 Hz is much higher than that of 40 Hz. This indicates an occurring of resonance at the power frequency of 50 Hz.

This can be also shown in figure (4), by comparing the 1/3 Octave, shows a maximum noise reduction when removing the radiators of about 3dB at 50Hz

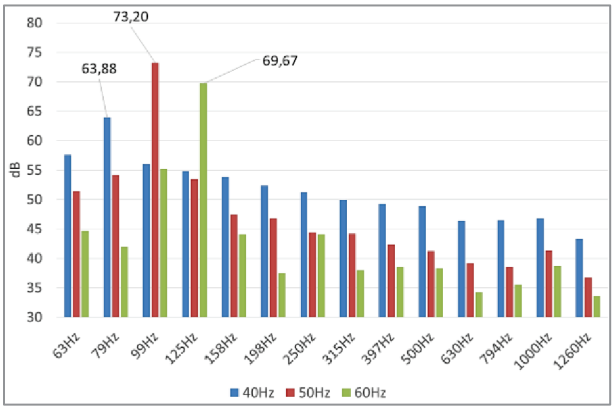

Fig 3: 1/3 Octave band analysis of the three measured frequencies 40, 50 and 60 Hz.

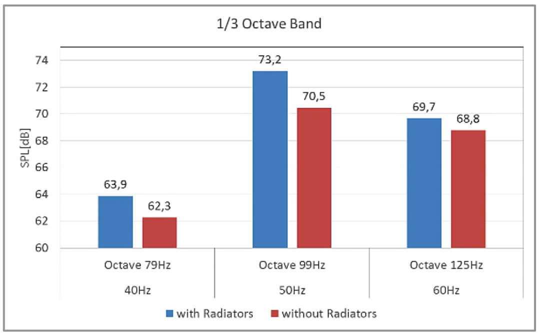

Fig 4: Comparison of the main 1/3 octave bands of the three frequencies (40, 50 and 60 Hz) for the same unit with- and without radiators.

FEM Simulation

The transformer tank is a complex geometry with screws, holes, additional connecting structures, stiffeners, …etc. Thus, investigation of geometry simplifications and mesh study are performed to define the effective model prior to FEM simulation. For the same case study power transformer, analyzing the resulting natural-frequencies and mode shapes around 100 Hz shows an occurrence of resonance in this frequency range in the HV side, which is in consistence to the noise measurements indication. Figure (5) shows the mode shape where the resonance occurs in the HV side at frequency ~100 Hz.

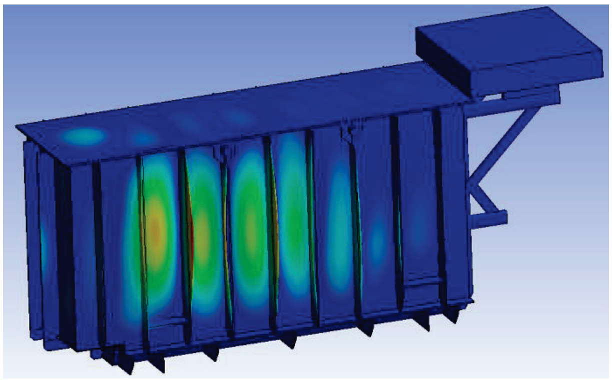

Fig 5: local tank resonance on the HV side of the transformer

Hammer-impulse Test

Hammer-impulse around all tank sides between vertical stiffeners to search for local resonance around 100 Hz is conducted.

to investigate the mode-shape, five points on each side are measured (center, top, bottom, right and left), figure (6).

Fig 6: Arrangement of points for hammer-impulse test for measuring mode-shapes and their corresponding natural frequencies on tank walls

hammer-impulse test measured mode-shapes and its corresponding frequencies are compared with simulation results. Matching between them is shown in figure (7).

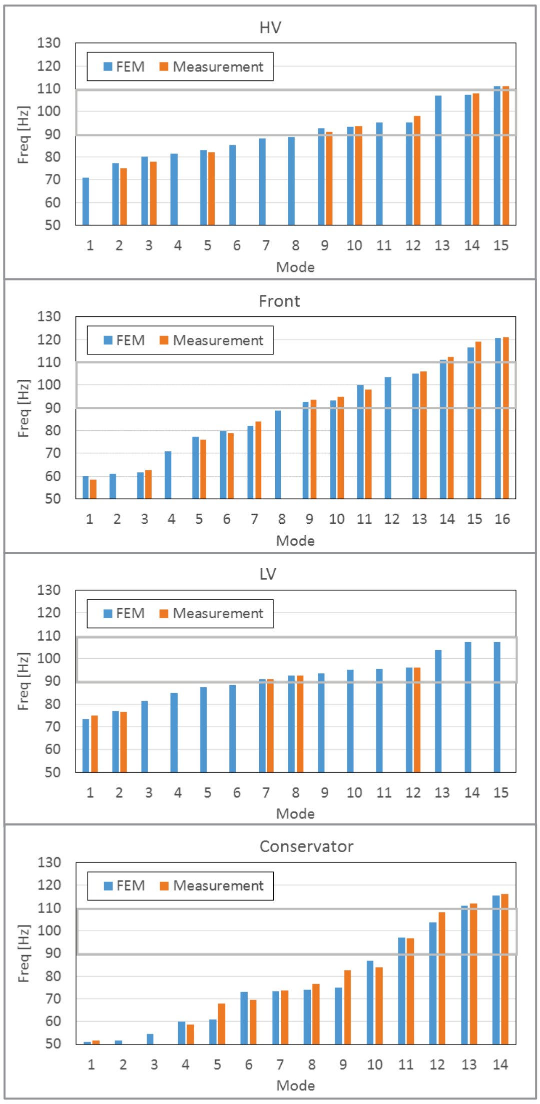

Fig 7: Matching between calculated and measured tank resonances

Tank solutions

The investigation procedures have proven the occurrence of tank resonance on the LV side of the case study transformer.

Adding stiffeners to the tank wall is optimized via FEM simulation as a feasible option to shift the frequency out of the range around 100 Hz. Simulations performed for optimizing position, number, dimensions, angle, and cross-section of the stiffeners to shift the resonance to higher frequency and to guarantee no danger of appearing new local resonances neither at HV side nor all other sides.

Fig 8: Transformer tank with additional optimized diagonal stiffeners

The optimum design of stiffeners on the tank, figure (8) shows that the resonance frequency at the HV side is increase to about 107 Hz, as well as, a shifting in all other sides without unexpected resonance occurrence around the tank sides.

Noise measurement of the unit without radiators after tank modification shows a reduction on noise of about 2 dB in comparison to the original design, figure (9).

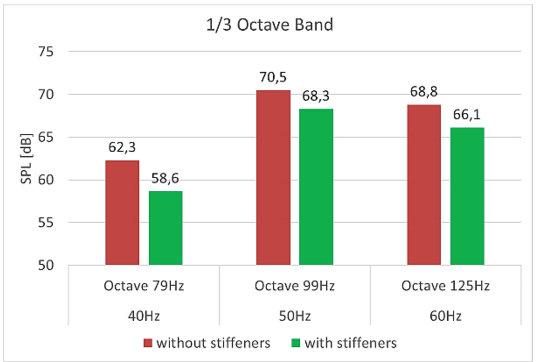

Fig 9: Comparison of the main 1/3 octave bands of the three frequencies (40, 50 and 60 Hz) for the same unit without radiators with- and without optimized additional stiffeners.

In addition, the positioning of the stiffeners serves in removing the augmentation of noise by damping the radiators vibration. The cross-section and the connection of the additional stiffeners to the original vertical stiffeners are optimized to improve the corrosion resistance, easy welding and high moment of inertia.

Final noise measurement of the same unit after tank modification shows a reduction on noise of about 5 dB, figure (10).

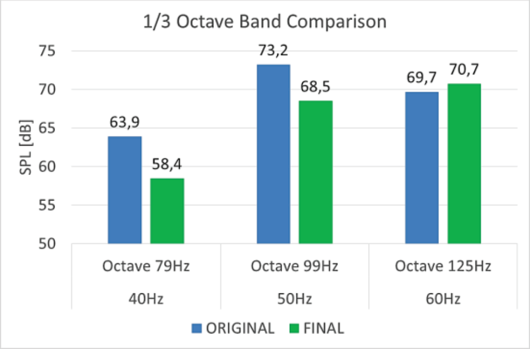

Fig 10: Comparison of the main 1/3 octave bands of the three frequencies (40, 50 and 60 Hz) for the same unit with and without additional stiffeners

Conclusions

The novel developed systematic procedure to first detect the resonance in the tank and then controlling its effect on noise has proven its reliability in practice. The main conclusions are as follow:

- Tank resonance can add a significant contribution to the load-noise when it arises in the range of twice power frequency
- Systematic measurements deliver information on tank resonance
- The study shows the ability to calculate the natural frequencies of the tank with a high accuracy, which is validated by applying hummer-impulse at specific places on the tank walls
- The control of tank resonance is done by shifting the natural-frequencies via optimizing additional stiffeners
- Results show that by following the presented procedure on a case study transformer it is possible to reduce the noise by about 5 dB

Literatures

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