Effect of Sensor Location on Vibro-Acoustic Measurement-Based Transformer Condition Assessment

The failing of transformers bears high costs both towards the providers and the consumers with key factors ranging from restoration costs, labour and replacement costs and lost opportunity costs. Proper condition monitoring of transformers are much needed.

By Jakob Pallot

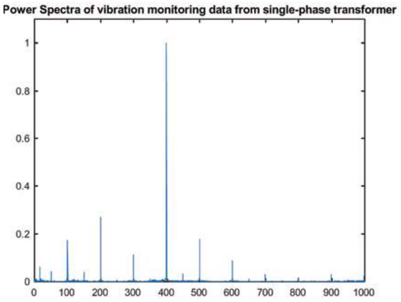

Figure 1 *Power spectra from test laboratory single-phase transformer from vibration monitoring*

Proper condition monitoring practice falls under either offline or online condition monitoring with online monitoring being superior in principal to offline measurements. Whilst numerous techniques are capable of monitoring key transformer components, there is no established online monitoring technique for the winding and core structure, the components most at risk of failure.

An important factor that condition monitoring techniques need to meet is for the measured data to relate directly to the condition of the component being measured. In the case of the winding and core structure, the captured measured data should relate directly to the winding and core structure with known markers such as external or internal influence whether this be current or voltage changes to be understood. Additionally, assessment of the data preferably needs to be undertaken on a semi regular basis. Whilst measurements that require sporadic events such as SFRA which uses an impulse (lightning strike) are not necessarily detrimental, they can make online condition monitoring difficult to implement if the event does not take place on a regular occurrence.

STRONG ONLINE CONDITION MONITORING TECHNIQUE

Since transformer vibration is strongly tied to the operation / condition of the winding and core structure, vibration monitoring is the likely candidate for a strong online condition monitoring technique. The significant benefit of vibration monitoring is it offers a non-intrusive and cost-effective monitoring technique and is implemented generally with accelerometers placed on the surface of the transformer to capture vibrations generated inside the transformer, although Laser Doppler Vibrometry (LDV) can be also be used.

Within the field of vibration monitoring, two main methods exist, modal analysis and steady-state vibration analysis. Modal analysis investigates how a structure's natural frequencies change with respect to structural changes. At current stance, modal analysis faces significant challenges with industrial adoption in an online application due to its inability to be applied from vibrations caused during normal operations of the transformer. The field of forced vibrations, however, investigates the relationship between a transformer's structural health and the steady-state vibrations generated during standard operation and is the vibration monitoring field currently expected to have the best chance at success within industry adoption.

During standard operation, the winding and core structure generates vibrations at harmonic intervals starting at twice the power frequency. For example, in Australia, the power frequency is 50 Hz, hence vibrations will be seen at 100 Hz, 200 Hz, 300 Hz, and so on (Figure 1).

Whilst there are numerous factors that affect the propagation of transformer vibrations, whether this be structure deformations, temperature fluctuations, as well as fluid viscosity, density, and flow changes, a significant factor that has not been presented in literature is the influence of standing waves on the transformer surface. Furthermore, a distribution of the vibrations around the transformer had not appeared to be mapped.

With this in mind, we investigated how vibrations differ around the transformer whilst at steady-state vibration levels and how these results related to Finite Element Modelling (FEM) simulation results. To achieve this, as shown in Figure 3, four accelerometers were placed on the surface of a transformer with a cylindrical tank, the transformer was then energised, and measurements were taken once steady-state was reached. The transformer was then de-energised, accelerometers were moved to the adjacent position, and the process was repeated. This was carried out around the entire transformer.

The results were then converted into power spectra and overlayed onto a cylindrical structure, representing the transformer tank, for each of the different frequencies. Instead of seeing areas on the transformer containing vibration hotspots such as areas closest to the winding, different uniform distributions were seen at each of the different frequencies.

Figure 2 shows acoustic pressure FEM simulations using the Modal Acoustics

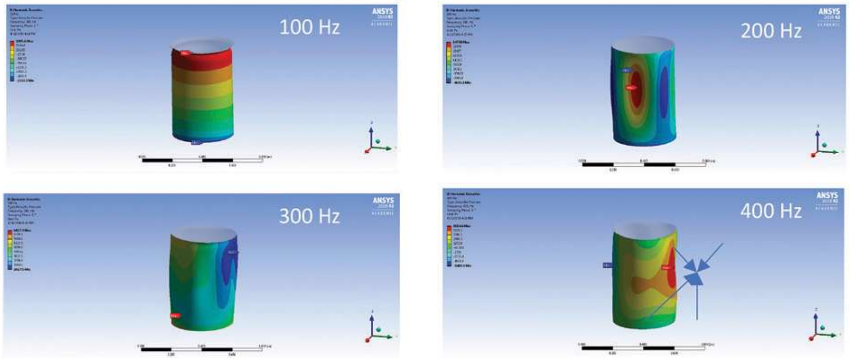

Figure 2 *FEM simulation of single-phase transformer showing different acoustic pressure distribution on transformer tank surface*

module in ANSYS for the different frequencies. Within the ANSYS module, a mass source was inserted into the space of the HV and LV windings to simulate acoustic pressure (vibrations) being generated from that space.

Likewise, the test laboratory single-phase transformer as seen below in Figure 3 was used to map the vibrations on the transformer and compare with the results obtained above in Figure 2.

Figure 3 *Test laboratory single-phase transformer*

Figure 4 presents the vibration distribution obtained from the different frequencies overlayed onto a cylinder structure.

From both figures, FEM simulations, and vibration measurements, it is clear s that the transformer primarily deforms irrespective of the location of the internal components. Said differently, accelerometer placement appears to not be dependent upon key locations such as windings, bushings or tap changer.

The main recommendation from these findings is to separate the power spectra of the vibrations into different frequency categories and analyse them independently. What this means is accelerometers need to be placed in locations to target a specific frequency. For example, from the above Figure 4, monitoring and analysing the 100 Hz frequency should be consigned strictly to the top of this model transformer. If, however, monitoring of the 100 Hz frequency is done at the bottom of the transformer where the Signal-Noise-Ratio (SNR) is comparatively lower than at the top of the transformer, structural changes such as a winding deformation, may go unnoticed or the severity of it.

An important point from this recommendation is whilst this is applied strictly to a cylindrical geometrically simple single-phase transformer, the same concept still will apply to other transformers, in particular three-phase transformers.

Jakob Pallot (j.pallot@uq.net.au) is a PhD Candidate at the University of Queensland. His interests lie in the condition monitoring and the improvement and development of new and existing techniques.

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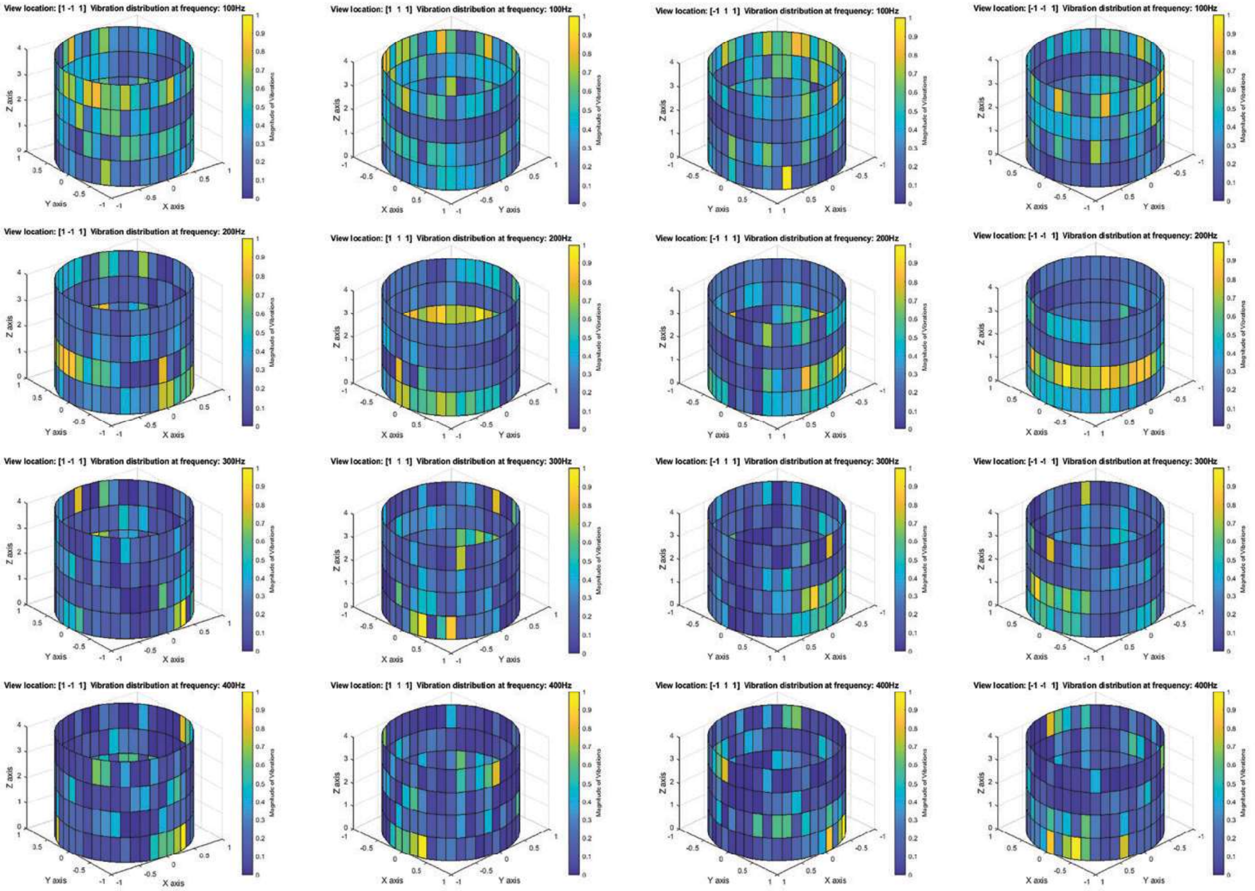

Figure 4 *Vibration distribution around test laboratory single-phase transformer*