Lugg-Widger P
*Cardiff University*
*School of Engineering*

Pearson M
*Cardiff University*
*School of Engineering*

Anderson P
*Cardiff University*
*School of Engineering*

SUSTAINABLE ENERGY

# Acoustic Noise Emission Detection and Location Analysis from a Scaled Laminated Transformer

In this paper the vibrational noise of a small scale laminated transformer core is measured to study the magnetic phenomena known as magnetostriction which generates its characteristic hum. Noise frequency measurements are recorded using traditional microphone arrangements and a highly sophisticated 2D acoustic camera array to trial its application. The recorded results examine the frequency harmonics of the transformer noise and analyze a method for specific frequency location detection.

*Keywords:*
*Power transformer, noise, acoustics, magnetostriction.*

*Corresponding author:*
*WidgerP@cardiff.ac.uk*



P. Lugg-Widger, M. Pearson, and P. Anderson, ‘Acoustic Noise Emission Detection and Location Analysis from a Scaled Laminated Transformer’, *Proceedings of the Cardiff University Engineering Research Conference 2023*, Cardiff, UK, pp. 140-144.

**doi.org/10.18573/conf1.af**

## INTRODUCTION

Electrical power transformers exhibit three sources of noise whilst in operation: core noise caused by a combination of the magnetostriction phenomena and Maxwell forces at joints, load noise caused by electromagnetic forces in the windings and structural components due to current leakage flux and noise generated by the operation of cooling and fan equipment [1]. It is beneficial to reduce the noise produced by electrical transformers as the continuous tone and character can cause irritation and discomfort to humans. This is especially important in urban areas where high density populations require increasing transformer size, and hence noise, in close proximity to many individuals. In some countries maximum permissible noise levels have been stipulated varying in values from normal levels in rural areas to lower values in large urban environments. Cities such as New York have even introduced ultra-low levels such is the importance of this issue [2].

Currently new transformer cores are designed to uniformly distribute magnetic flux with low levels of flux harmonics in the core and joints. Transformer cores are held by complex clamping structures and are designed to uniformly clamp laminations to avoid deformations. Transformer tanks must avoid noise and resonances therefore reducing sound radiation from the core and windings [3]. In order to meet future noise restrictions it is necessary to further examine and understand the total process of sound generation from magnetostriction, transmission and radiation in order to design and build future environmentally friendly 'quiet' transformers.

British and international standards, IEC 60076-10 [4] and IEC 61672 [5], detail how power transformer noise should be measured, however, varying methods of reporting results and equipment allows for a wide variation in results and evaluation. Currently some results measure total collective noise level of the transformer (dBA) and others the individual recordings from components such as core and fan noise, total noise level or loaded/unloaded transformer noise [1].

Core noise due to magnetostriction is caused by small mechanical deformations in the core laminations when a magnetic field is applied. These small changes in the dimensions of the core are independent of flux direction and therefore occur at double the supply frequency i.e 100Hz for a 50Hz supply. Furthermore, the effect of magnetostriction can introduce higher frequency harmonics of multiple orders above the initial 100Hz. Therefore, core noise has components at multiples of 100 or 120Hz (for 50Hz and 60Hz transformers respectively) [6,7]. In this paper the vibration of a small scaled laminated core transformer is measured whilst powered under no-load conditions and the magnetic phenomena known as magnetostriction further examined to generate a characteristic hum classified as "noise". The noise measurements are recorded using a traditional microphone circular ring arrangement, a 2D traditional microphone array and finally a highly sophisticated 2D acoustic camera array to trial its application.

## MATERIALS AND METHODS

The test arrangement used throughout experimentation in this paper consisted of a scaled three phase transformer, under no-load conditions, powered from a three phase regulator and individual variacs or variable transformers for each phase as shown in Fig. 1. Throughout testing the direct voltage and current from the scaled transformer was monitored and recorded through a digital power meter. The voltage and current of the variacs that adjust the voltage induced in the transformer windings are directly adjustable using a National Instruments data acquisition card connected to a computer control system shown in Fig. 1. In this paper the scaled transformer dimensions were 550(W)x550(H)x80(D) and the clamping bolts of the support structure were intentionally left loose. The transformer has an applied phase voltage of 50V which is equivalent to an average 1.5T magnetic flux density.

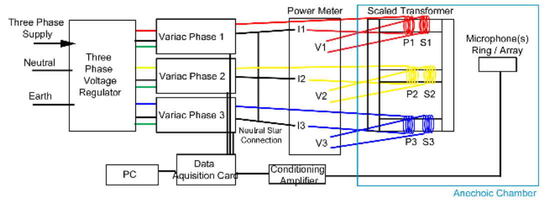


Fig. 1. Transformer noise electrical test arrangement and data measurement setup.

The conventional microphone ring arrangement consisted of 8 prepolarized condenser microphones and the array consisted of 9 of the same condenser microphones all with a frequency range of 8-12500 Hz with a response of 27.2 mV/Pa at 1000 Hz. Each of these microphones were fed into a preamplifier and then into a conditioning amplifier to enable the clearest and largest signal output. Individual signals from each microphone fed through the conditioning amplifier was monitored and recorded in real time using a data acquisition card and computer.

The conventional microphones are arranged in a ring or 2D array arrangement 70cm from the transformer core such as could be achieved using the anechoic chamber. For the ring arrangement there were six microphones positioned to directly oppose each side of each transformer limb and two microphones either end of the transformer as shown in Fig. 2. For the array arrangement each microphone was placed 22cm apart horizontally and 20cm apart vertically so that a total of 9 microphones in a 3x3 array was constructed in a 40cm(H) x 44cm(W) arrangement to directly oppose one side of each transformer limb as shown in Fig. 3 overleaf.

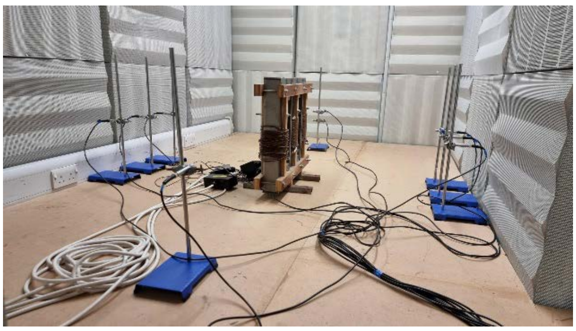

Fig. 2. Conventional eight microphone ring test arrangement placed 70cm from the transformer.

Fig. 3. Conventional nine microphone array test arrangement placed 70cm from the transformer.

The highly sophisticated near field 2D acoustic camera [8] that was utilized for the second half of the testing consisted of an array of 96 microphones with a frequency range of 40 Hz to 2 kHz for nearfield SONAH measurements (larger ranges are possible for far field measurements). This array was connected to a computer via a data acquisition system to record both microphone and camera data using the proprietary software.

The scaled transformer and microphone array are enclosed within an anechoic chamber to reduce background noise and interference and ensure the recordings taken refer specifically to the noise produced by the transformer as shown in Fig. 4. The transformer and acoustic camera were centered and placed 4cm apart as show in Fig. 5 providing maximum coverage of the transformer core.

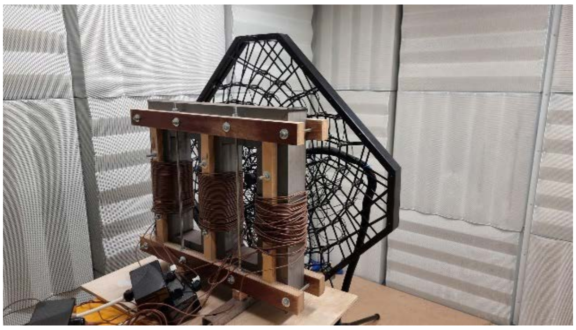

Fig. 4. Scaled electrical transformer and acoustic camera array inside the anechoic chamber.

Fig. 5. Testing arrangement of acoustic camera and scaled electrical transformer.

## RESULTS

Initially a background noise level recording was taken using the conventional microphones prior to any power being provided to the transformer as shown in Fig 6. The results from the background recording in Fig. 6 show that even in an anechoic chamber not all sources of background noise can be eliminated especially below 100Hz.

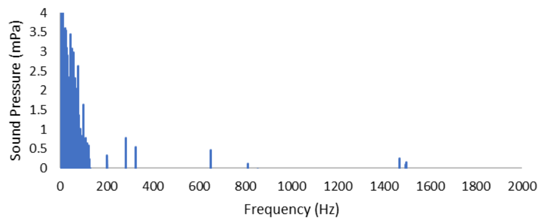


Fig. 6. Background noise level inside the anechoic chamber recorded using conventional microphones in array formation.

Following this the conventional microphones were arranged in a ring formation and a recording taken for the transformer at 1.5T as shown in Fig. 7 Next the same microphones were arranged in an array formation, as described in the methods section, and the data recorded for the transformer at 1.5T is shown in Fig. 8.

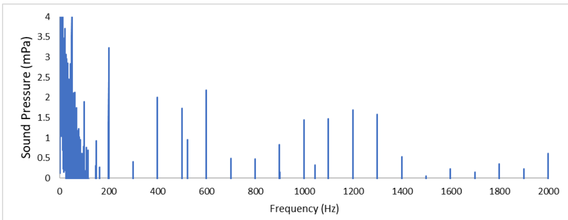


Fig. 7. Noise level of the transformer at 1.5T inside the anechoic chamber recorded using conventional microphones in ring formation.

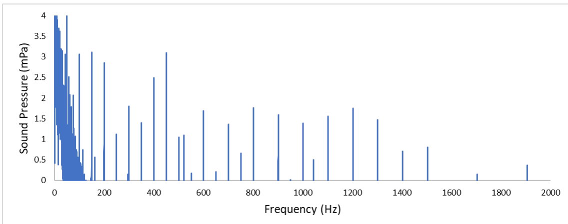


Fig. 8. Noise level of the transformer at 1.5T inside the anechoic chamber recorded using conventional microphones in array formation.

Following this the conventional microphones were replaced with the sensitive acoustic camera array and a new recording undertaken for the background noise level of the anechoic chamber without the transformer powered as shown in Fig. 9.

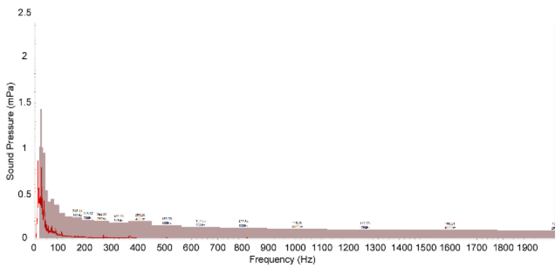


Fig. 9. Background noise level from inside the anechoic chamber recorded using the acoustic camera array.

Finally, the acoustic camera array was used to record the noise from the transformer at 1.5T inside the anechoic chamber as shown in Fig. 10.

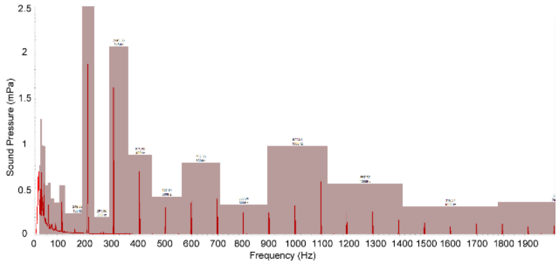


Fig. 10. Noise level of the transformer at 1.5T from the scaled transformer inside the anechoic chamber recorded using the acoustic camera array.

The results from Fig. 10 were further enhanced using the acoustic camera array to map the noise detection from the 96 microphone array to a precise location on the camera recordings using nearfield SONAH location detection. The acoustic camera location mapping results for the 300Hz peak in Fig. 10, with the transformer at 1.5T, is shown Fig. 11.

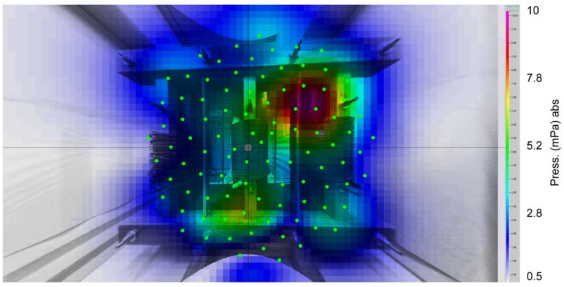


Fig. 11. 300Hz Noise detection for the scaled transformer at 1.5T inside the anechoic chamber recorded using the acoustic camera array.

## DISCUSSION

In Fig. 6 and Fig. 9 the background noise levels in the anechoic chamber from two comparative sets of microphone arrays were recorded. The figures indicate that both sets of microphones were comparable and show the same background noise below 100Hz with small amounts of noise detected around 300Hz. Fig. 6 and Fig. 9 also show that the low levels of noise in the anechoic chamber allows for scientific experimentation and measurements to be undertaken from the noise produced by a magnetic transformer core when resonating due to magnetostriction.

In Fig. 7 and Fig. 8 the same conventional microphones were used in an array and ring formation to produce a recording of the noise from the transformer at 1.5T. Fig. 7 and Fig. 8 show the increased noise levels recorded at 100Hz caused by magnetostriction at double the supply frequency. The results also clearly show the harmonics produced at multiples of 100Hz including 200Hz, 300Hz etc all the way up to 1400Hz and beyond. These harmonics generally decline in magnitude as the frequency increases. In Fig. 8 the array formation also indicates additional harmonics at 150Hz, 250Hz etc up to 800Hz which do not appear in the ring formation and will require further examination and experimentation to understand.

In Fig. 10 the acoustic camera array is used to record the noise from the transformer at 1.5T. In comparison to Fig. 7 and Fig. 8. the results obtained by the acoustic camera in Fig. 10 are broadly equivalent and clearly show the transformer noise produced at 100Hz and the harmonic multiples at 200Hz, 300Hz and beyond. Furthermore, the acoustic camera array was used to highlight and identify sources of noise location overlayed on the photos from the camera which is possible due to the large number of microphones in the array. In Fig. 11 the noise for the 300Hz signal, taken from Fig. 10, detected from the acoustic camera array indicates the top right corner of the transformer core and structure was the source of noise which was resonating significantly.

## CONCLUSIONS

In conclusion this research highlights the comparative noise measurements from a scaled transformer at 1.5T that can be undertaken using both a conventional microphone setup and a novel acoustic camera array. It indicates that the continued use of an acoustic camera array to further understand sources of resonating transformer harmonics can be undertaken and further examination is required to understand noise source location and frequency in greater detail. Future research will examine the location of transformer noise at varying magnetic flux densities with different degrees of clamping levels of the core structure to understand the fundamentals of magnetostriction in a complex structure and a transformer core.

***Acknowledgments***
*The authors would like to acknowledge the support of the Welsh Government Welsh European Funding Office (WEFO) project MAGMA. The authors would also like to acknowledge the Cardiff University Research Infrastructure Fund that supported the acquisition of the acoustic camera utilized in the experimentation of this paper.*

***Conflicts of interest***
*The authors declare no conflict of interest.*

## REFERENCES

[1] R. Girgis, J. Anger, and D. Chu, 'The sound of silence: Designing and producing silent transformers', *ABB Review*, vol. 2, pp.47-51, 2008.

[2] R. Girgis, M. Bernesjo, S. Thomas, J. Anger, D. Chu, and H. Moore, 'Development of Ultra-Low Noise transformer technology', *IEEE Transactions on Power Delivery*, vol. 26, issue 1, pp. 228-234, Jan. 2011. doi.org/10.1109/TPWRD.2010.2070812

[3] G. Shilyashki, H. Pfutzner, P. Hamberger, M. Aigner, A. Kenov, and I. Matkovic, 'Spatial distributions of magnetostriction, displacements and noise generation of model transformer cores', *International Journal of Mechanical Sciences*, vol. 118, pp.188-194, 2016. doi.org/10.1016/j.ijmecsci.2016.09.022

[4] IEC/TC14 / PEL/14, *British / International Standard BS/IEC 60076-10, Power Transformer, Determination of sound levels,* Feb. 2020.

[5] IEC/TC29 / EPL/29, *British / International Standard BS/IEC 61672, Elctroacoustics. Sound level meters, Specifications.,* Dec 2013.

[6] R.S. Masti, W. Desmet, and W. Heylen, 'On the influence of core laminations upon power transformer noise', *Proceedings of ISMA2004*, pp. 3851-3862, 2004.

[7] H. Jingzhu, L. Dichen, L. Qingfen, Y. Yang, and L. Shanshan, 'Electromagnetic vibration noise analysis of transformer windings and core', *IET Electric Power Applications 2016*, vol. 10, issue 4, pp. 251-257, 2016. doi.org/10.1049/iet-epa.2015.0309

[8] gfai tech Fibonacci array acoustic camera, further specifications: www.gfaitech.com

*Proceedings of the Cardiff University Engineering Research Conference 2023* is an open access publication from Cardiff University Press, which means that all content is available without charge to the user or his/her institution. You are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles in this publication without asking prior permission from the publisher or the author.



E. Spezi and M. Bray (eds.) 2024. *Proceedings of the Cardiff University Engineering Research Conference 2023.* Cardiff: Cardiff University Press.
doi.org/10.18573/conf1

*Cardiff University Engineering Research Conference 2023* was organised by the School of Engineering and held from 12 to 14 July 2023 at Cardiff University.

The work presented in these proceedings has been peer reviewed and approved by the conference organisers and associated scientific committee to ensure high academic standards have been met.

First published 2024

Cardiff University Press
Cardiff University, PO Box 430
1st Floor, 30-36 Newport Road
Cardiff CF24 0DE

cardiffuniversitypress.org

Editorial design and layout by
Academic Visual Communication

ISBN: 978-1-9116-5349-3 (PDF)