Magnetic structure for load noise control in transformers

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ABSTRACT
A magnetic structure is a ring-shaped object composed of ferromagnetic material, designed to be positioned at the top and bottom ends of a transformer winding. Its primary function is to redirect a significant portion of the radial component of stray magnetic flux into the axial direction, thereby preventing the flux from approaching the tank wall. The radial component of the stray magnetic flux generates axial forces at the winding ends, which are the main source of winding vibration and consequent load noise. Thus, the MSR aims to reduce load noise by mitigating these axial forces. While the concept showed some noise reduction potential, the simulation results were not significant enough to justify further development.

1 INTRODUCTION

A magnetic shield ring (MSR) is a ring-shaped object composed of ferromagnetic material, designed to be positioned at the top and bottom ends of a transformer winding, as depicted in Figure 1. Its primary function is to redirect a significant portion of the radial component of stray magnetic flux into the axial direction, thereby preventing the flux from approaching the tank wall (Mousavi, 2024). The radial component of the stray magnetic flux generates axial forces at the winding ends, which are the main source of winding vibration and consequent load noise. Thus, the MSR aims to reduce load noise by mitigating these axial forces. Additionally, the MSR reduces eddy current losses caused by the radial component of stray magnetic flux impacting various transformer structural parts and diminishes the axial forces due to short-circuit currents in the windings.

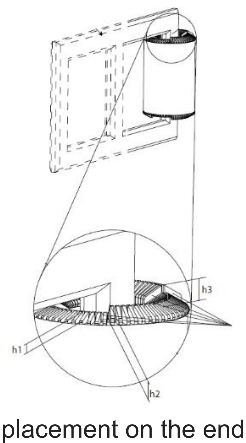

Figure 1: MSR placement on the ends of the winding

2 Results

2.1 MSR on a 3-phase SPT design (42.7 MVA)

A 3D simulation of a 50Hz electrical transformer (42.7MVA, it is called as Small Power Transformer (SPT)) was conducted using COMSOL Multiphysics 6.2. The focus on noise reduction at 100Hz is crucial since it is a 50Hz electrical transformer. Figures 2 and 3 illustrate the CAD geometry of the SPT transformer and the Perfectly Matched Layer (PML) surrounding the transformer, respectively. Figure 4 presents the radiated acoustic power, and to understand the underlying cause, pressplate axial power and tank piston power, which are critical factors in noise generation, were analyzed and are shown in Figures 5 and 6, respectively. Table 3 demonstrates noise reduction across a broader frequency band, showing an approximate 3dB reduction which is not enough to further carry out experimental investigation. In summary, although the concept was validated, the achieved noise reduction is insufficient to justify further pursuit of the MSR concept. Table 2 indicates that the application of MSR results in a reduction of Maxwell forces, which correlates with the observed noise reduction.

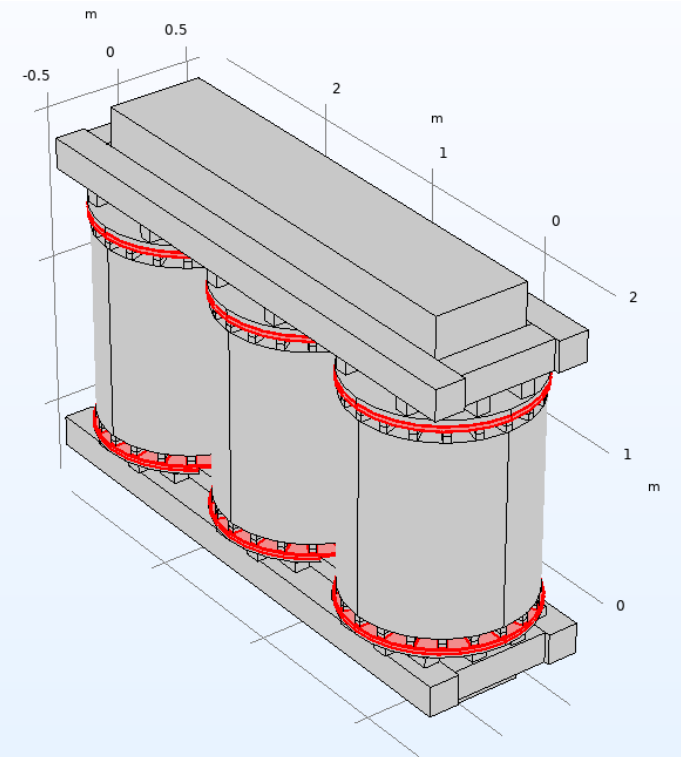

Figure 2: Transformer CAD geometry (MSR is shown in red colored domains)

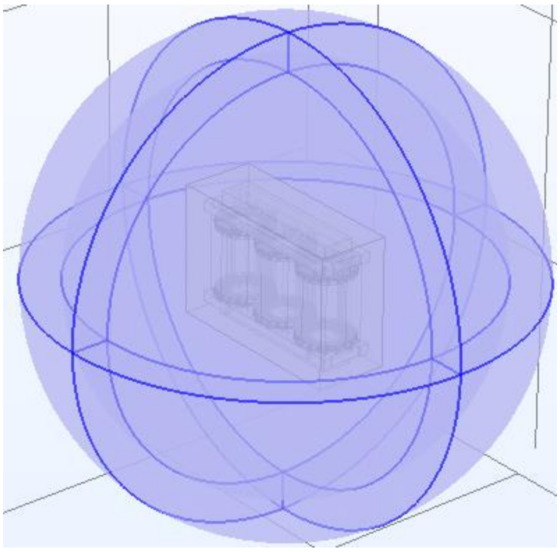

Figure 3: Perfectly matched layer (PML) around the transformer

Table 1: Noise reduction of SPT design at different frequency band

Frequency Band (*Hz*)	Acoustics Power (*dB*)		Noise reduction (*dB*)
	No MSR	With MSR	
80 - 120	68.4653	68.1510	0.3
60 - 140	69.7278	67.7047	2.02
40 - 160	72.6604	69.3152	3.36
40 - 200	78.6354	76.3359	2.3

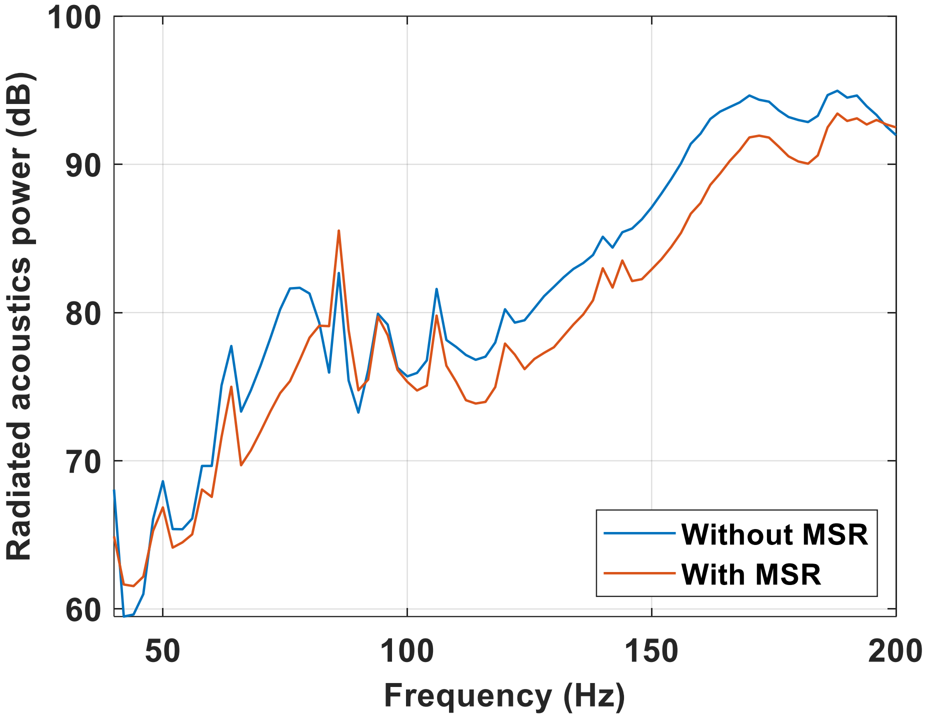

Figure 4: Radiated acoustics power from SPT design

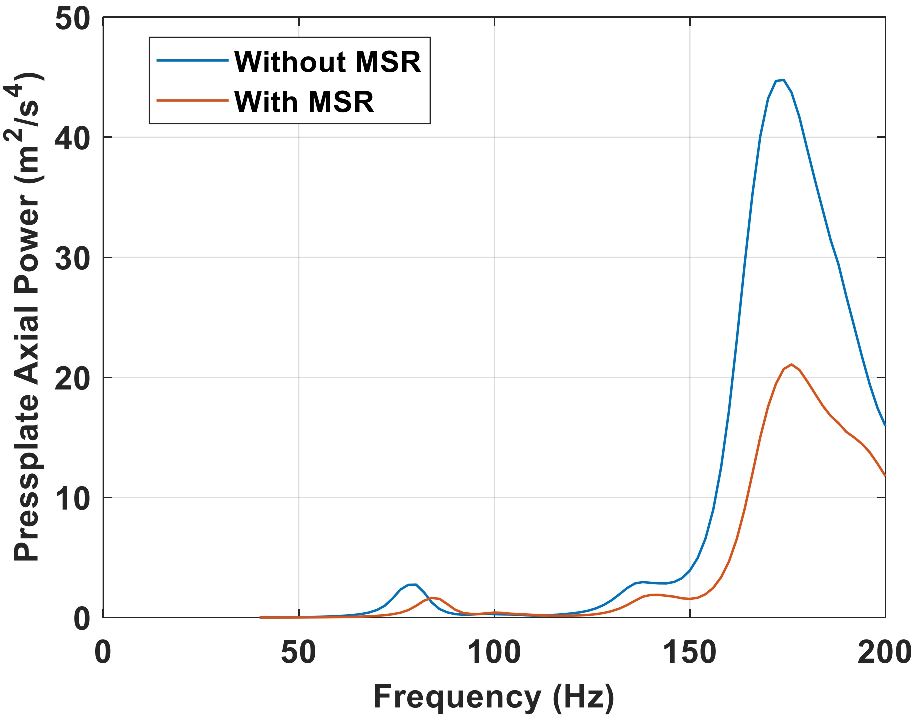

Figure 5: Pressplate axial power from SPT design

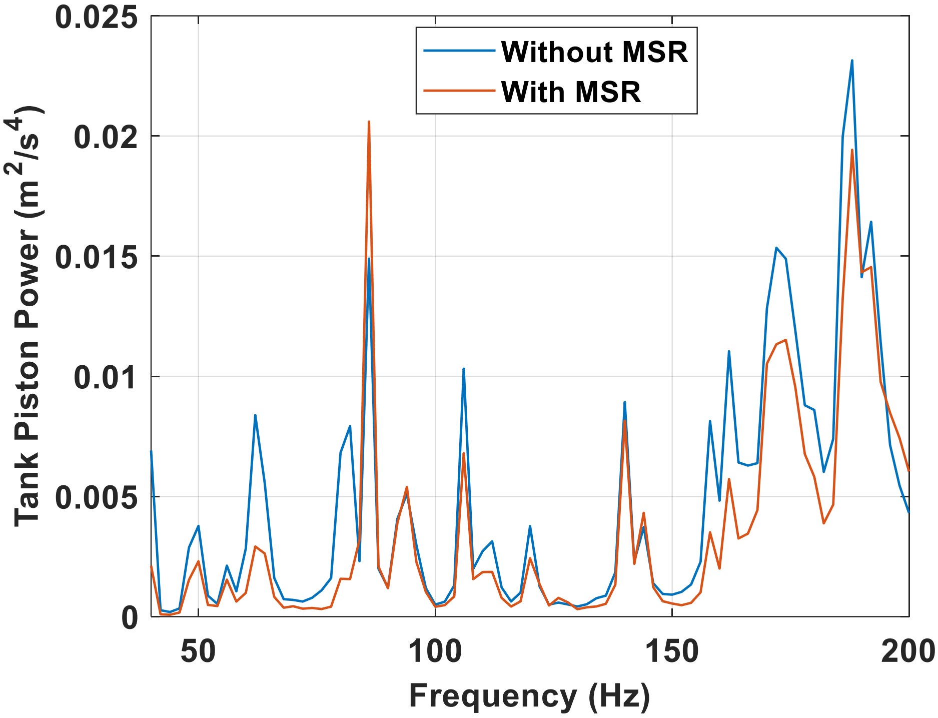

Figure 6: Tank piston power from SPT design

Table 2: Maxwell force on tank wall with and without MSR

50 Hz	Without MSR	With MSR
Maxwell Force on Tank Wall in X-Direction (N)	0.003+0.007i	0.001+0.002i
Maxwell Force on Tank Wall in Y-Direction (N)	0.012+0.0034i	0.005+0.002i
Maxwell Force on Tank Wall in Z-Direction (N)	-0.004-0.005i	-0.001-0.003i
Maxwell force magnitude	0.095562	0.045376

2.2 MSR on a 3-phase MLPT design (140 MVA)

The MSR concept was also applied to a 60Hz electrical transformer of the MLPT design (Medium Large Power Transformer, 140 MVA). The resulting acoustic power is illustrated in Figure 7, and the corresponding noise reduction across a broader frequency band is presented in Table 3. It is important to note that noise radiation at 120Hz is critical for a 60Hz electrical transformer. The application of the MSR did not significantly alter the radiated acoustic power, resulting in minimal change in the overall noise reduction across the broader frequency band.

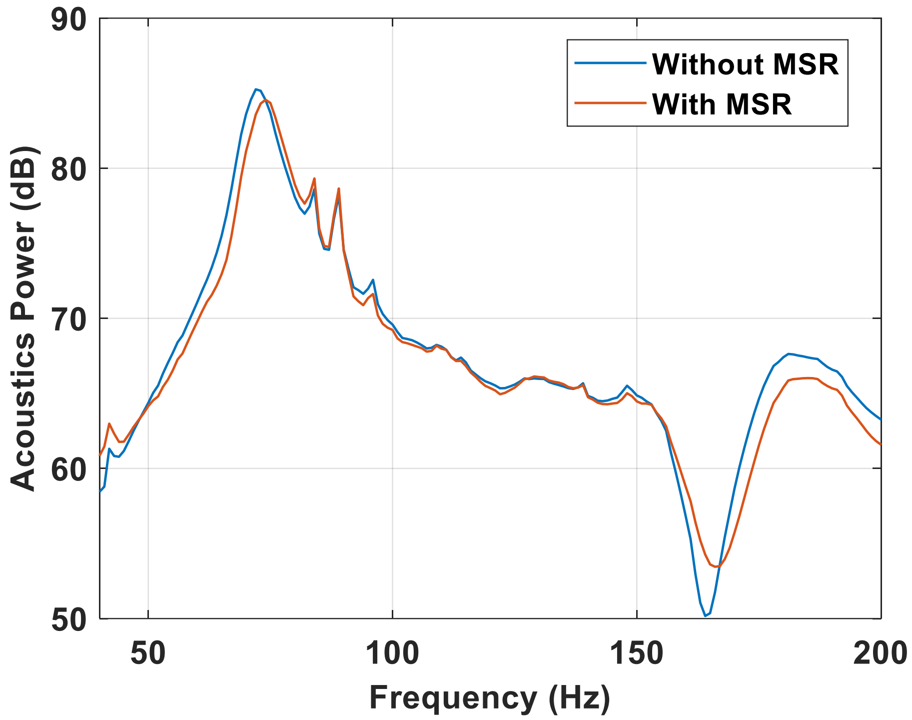

Figure 7: Radiated acoustics power from MLPT design

Table 3: Noise reduction from MLPT design at different frequency band

Frequency Band (Hz)	Acoustics Power (dB)		Noise Reduction (dB)
	No MSR	With MSR	
100 - 140	56.8575	56.7083	0.15
80 - 160	60.5216	60.7251	-0.2
60 - 180	64.8100	64.2768	0.6
40 - 220	63.2802	62.7221	0.5

3 Discussions

The limited noise reduction observed with the application of Magnetic Shield Ring (MSR) can be attributed to several factors:

1. Frequency Dependence:
   - The noise reduction potential was strongly dependent on frequency. The simulations showed very little impact at the target frequency of 400Hz, which is critical for transformer noise reduction.
2. MSR Configuration:
   - Different configurations of the MSR (patches and half pressplates) were tested, but neither configuration showed significant noise reduction at the target frequency.
3. Magnetic Properties:
   - The orientation and magnetic properties of the MSR did not significantly affect noise reduction. Simulations with different relative permeabilities in various directions showed no appreciable change in noise levels.
4. Maxwell Forces:
   - While the MSR reduced Maxwell forces on the tank wall, this did not translate into significant noise reduction. The reduction in axial forces and eddy current losses was not enough to impact the overall noise levels.

Overall, these factors combined to limit the effectiveness of the MSR in reducing transformer noise, leading to the conclusion that further development was not justified.

4 Conclusions

The key findings from the Magnetic Shield Ring (MSR) project are as follows:

1. **3-phase SPT design (42 MVA) Transformer:**
    - 3D simulations showed approximately 3dB noise reduction across a broader frequency band.
    - The trend of the acoustics power curve was consistent with the concept.
    - However, the noise reduction was not sufficient to justify further development of the MSR.
2. **3-phase MLPT design (140 MVA) Transformer:**
    - Similar tests on MLPT design showed negligible changes in noise reduction.
    - The results reinforced the decision to halt the experimental investigation.

Overall, while the MSR concept demonstrated some potential for noise reduction, the simulations indicated that the reduction was not significant enough to continue development.

REFERENCES

Mousavi, S., Eriksson, G., Pradhan, M., and Daneryd, A. 2024. 'TRANSFORMER COMPRISING WINDING'. Patent no. US 11,990,268 B2.