Vibroacoustic Models of Air-Core Reactors

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The purpose of this paper is to provide an overview of the sound power radiation mechanism of air-core reactors and to describe the method that is used to calculate sound power by using the electrical load. Sound power radiation of an air-core reactor is related to the alternating current harmonics, the mechanical tension stiffness and, most importantly, the breathing mode resonance. An analytical model that is based on electrical loads and mechanical properties of the air-core reactor is developed to calculate radial and axial forces caused by the radial and axial magnetic induction fields. This study employs the hemispherical spreading theory, which is a simple and common method that is used to predict sound propagation. Additionally, a numerical model is proposed. In this, the excitation of the acoustic field that surrounds the reactor is introduced by considering the radial and axial displacements of the reactor’s windings, as the windings are subjected to the action of the radial and axial electromagnetic forces. Finally, a comparison is presented between analytical and numerical models and it is observed that the models are correlated.

NOMENCLATURE

\begin{align*}
B & \text{ magnetic induction field} \\
B_{radial} & \text{ radial magnetic induction field} \\
B_{axial} & \text{ axial magnetic induction field} \\
B_{avrg,z} & \text{ average magnetic induction field at } z \text{ direction} \\
B_{avrg,x} & \text{ average magnetic induction field at } x \text{ direction} \\
c_0 & \text{ speed of sound in air} \\
dl & \text{ infinitesimal element} \\
E & \text{ equivalent Young’s modulus} \\
E_{fib} & \text{ Young’s modulus of the fiberglass} \\
e & \text{ thickness of the winding} \\
e_{fib} & \text{ thickness of the fiberglass} \\
e_{iso} & \text{ thickness of the insulation} \\
F & \text{ electromagnetic force} \\
F_{avrg,x} & \text{ average force at } x \text{ direction} \\
F_{axial} & \text{ axial electromagnetic force} \\
F_{radial} & \text{ radial electromagnetic force} \\
F_{Z,avrg} & \text{ average force at } z \text{ direction} \\
f & \text{ frequency of the current} \\
G_{xy} & \text{ shear modulus at plane } xy \\
G_{xz} & \text{ shear modulus at plane } xz \\
G_{yz} & \text{ shear modulus at plane } yz \\
H & \text{ average height of the winding} \\
h_{ws} & \text{ height of the reactor without the spiders} \\
I_{eff} & \text{ effective current} \\
i & \text{ electrical current} \\
K & \text{ stiffness of a mechanical system} \\
K_{eq} & \text{ equivalent stiffness} \\
K_{f1b1} & \text{ stiffness of fiber layer 1} \\
K_{f1b2} & \text{ stiffness of fiber layer 2} \\
l & \text{ height of the material} \\
l_{ms} & \text{ perimeter of measurement surface} \\
L_P & \text{ average sound pressure} \\
L_P & \text{ sound pressure level} \\
L_W & \text{ sound power level} \\
M & \text{ mass of the winding} \\
N & \text{ number of turns per unit of length} \\
nbr & \text{ total average number of turns in the winding} \\
p & \text{ sound pressure} \\
p_0 & \text{ reference sound pressure} \\
R & \text{ average radius of the winding} \\
R_e & \text{ external radius of the winding} \\
R_i & \text{ internal radius of the winding} \\
r & \text{ distance point to source} \\
r_{sr} & \text{ distance source-receiver} \\
S & \text{ surface of contact between two materials} \\
S_m & \text{ surface area of measurement} \\
S_W & \text{ sound radiating surface} \\
S_0 & \text{ reference area} \\
t & \text{ time} \\
\nu_{rad} & \text{ average radial speed of the winding} \\
W & \text{ radiated sound power} \\
W_0 & \text{ reference power}
\end{align*}