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Analytical calculation of vibrations of electromagnetic origin in electrical machines

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ABSTRACT

Electrical motors are widely used and are often required to satisfy comfort specifications. Thus, vibration response estimations are necessary to reach optimum machine designs. This work presents an improved analytical model to calculate vibration response of an electrical machine. The stator and windings are modelled as a double circular cylindrical shell. As the stator is a laminated structure, orthotropic properties are applied to it. The values of those material properties are calculated according to the characteristics of the motor and the known material properties taken from previous works. Therefore, the model proposed takes into account the axial direction, so that length is considered, and also the contribution of windings, which differs from one machine to another. These aspects make the model valuable for a wide range of electrical motor types. In order to validate the analytical calculation, natural frequencies are calculated and compared to those obtained by Finite Element Method (FEM), giving relative errors below 10% for several circumferential and axial mode order combinations. It is also validated the analytical vibration calculation with acceleration measurements in a real machine. The comparison shows good agreement for the proposed model, being the most important frequency components in the same magnitude order. A simplified two dimensional model is also applied and the results obtained are not so satisfactory.

1. Introduction

Electrical motors are widely used in quite a number of applications; some of them, particularly those involving people, require the motors to satisfy comfort specifications, given in terms of vibrations and noise.

Each particular application has its own requirements, such as torque, power, efficiency, cost, size, noise, vibration. . ., so that it is necessary to consider them in an optimisation process, in order to reach the machine design that fits best the specifications. Thus, many multi-physical calculations are needed, which requires fast analytical calculations. In addition, due to the high excitation harmonics introduced by the inverters, high-frequency vibration calculations have to be carried out, so that analytical calculations are also preferable, because the more accurate FEM calculations require impractical huge

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Nomenclature

Acronyms

FEM	Finite Element Method
LPM	Lumped-parameter model
PDE	Partial Differential Equation
PMSM	Permanent Magnet Synchronous Motor
PSD	Power Spectral Density

Greek symbols

β	rotational angle [rad]
ϵ	strain
η	modal participation factor [m]
θ	circumferential position [rad]
κ	shear coefficient
λ	spatial order of the pressure
v	Poisson's ratio
ξ	damping coefficient
ρ	mass density [kg/m^3]
ϕ	phase lag of the harmonic response respect to the force [rad]
χ	slot filling factor
ψ	phase of the pressure component [rad]
ω	circular frequency [rad/s]
Λ	amplitude of the vibratory response [m]

Symbols

a	mean shell radius [m]
b	width [m]
f	frequency [Hz]
h	shell thickness or height [m]
k	bending strain
l	length [m]
m	axial mode
n	radial-tangential mode
p	number of pole pairs
q	pressure load [Pa]
s	surface [m^2]
t	time [s]
u	translational displacement [m]
x	axial position [m]
B	rotational mode shape
C	parameter dependent on mode shapes [m^2]
E	elasticity modulus [Pa]
F	parameter dependent on mode shape and excitation force distribution [m/s^2]
G	shear modulus [Pa]
M	bending moment per unit length [N]
N	normal force per unit length [N/m]
P	magnitude of the pressure component [Pa]
R	amplitude of the mode shape
S	amplitude of the mode shape
T	amplitude of the mode shape
U	displacement mode shape
V	amplitude of the mode shape
W	amplitude of the mode shape

Subscripts

$()_{equivalent}$	equivalent material property
$()_{inner}$	shell inner surface
$()_{slot}$	material property of the slot
$()_{teeth}$	material property of the teeth