Numerical Modelling of the Vibro-acoustic Behaviour of a Vehicle Gearbox

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(Received 15 December 2003; accepted 20 September 2004)

In this article, a global vibro-acoustic method to model gearboxes, which is based on the finite element and boundary element methods, is presented. The final aim of the method is to investigate the vibration and noise transmitted to the gearbox structure casing, which originate from the excitation caused by the gear train, in order to predict the vibro-acoustic parameters. Thus, the mathematical formulae that allow the determination of generalised stiffness matrices are presented in terms of the bearing and gear elements. A numerical model of the geared axle system that allows the estimation of the bearing reactions due to the gear forces transmitted is developed. This model takes into account the influence of modifying the gears teeth profile. The finite elements and boundary meshes were devised and generated in order to represent the gearbox. These meshes were used for the estimation of the acoustic parameters and for vibro-acoustic predictions.

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Nomenclature

A_j – loaded distance between the inner and outer raceway groove curvature centre, mm
Ar_j – radial component of A_j, mm
Aa_j – axial component of A_j, mm
B – total curvature factor, dimensionless
Bd – unloaded distance between the inner and outer raceway groove curvature centre, mm
c – speed of sound, m/s
$\mathbf{C}$ – damping matrix, Ns/m
d – rolling element diameter, mm
$\mathbf{F}$ – load vector, N
F_m – force on the spring which represents the gear mesh stiffness, N
Im_i – mass moment of inertia with respect to direction i, kg×m^2
k – wave number, m^{-1}
k_g – gear mesh stiffness, N/m
k_{ij} – stiffness constant elements of the bearing stiffness matrix, N/m
$\mathbf{K}$ – stiffness matrix, N/m
K_{cd} – load-deflection constant, N/m
$\mathbf{K_e}$ – gear mesh coupling stiffness matrix, N/m
$\mathbf{K_m}$ – bearing stiffness matrix, N/m
$\mathbf{K}_{Mi}$ – finite element matrix, N/m^n
m_i – gear mass, kg
$\mathbf{M}$ – mass matrix, kg
M_i – resultant moment in the i direction, Nm
p – pressure, N/m^2
$\mathbf{q}$ – displacement vector, m
$\dot{\mathbf{q}}$ – velocity vector, m/s
$\ddot{\mathbf{q}}$ – acceleration vector, m/s^2
r – curvature radius of the internal ring (for ball roller) or primitive radius (for cylindrical roller), m
r_e – curvature radius of the external ring of the ball bearing, m
r_i – curvature radius of the internal ring of the ball bearing, m
r_L – radial gap, m
R_{bi} – base circle radius of the i-th gear, m
R_{bc} – driven gear pitch radius, m
R_{bp} – driver gear pitch radius, m
R_i –resultant force in the i direction, N
X – main axis in the x-direction
Y – main axis in the y-direction
Z – main axis in the z-direction, or number of rolling elements

Greek Symbols

α_i – angular displacement in the i-direction, degrees
β_0 – contact angle without load, degrees
Δ_j – resultant elastic deformation of the j-th ball or roller element, mm
δa_j – axial displacement of the j-th roller element, mm
δ_i – translational displacement in the i-direction, mm
δ_E – resultant elastic deformation of the j-th ball element, mm
δr_j – radial displacement of the j-th roller element, mm
δ_R – resultant elastic deformation of the j-th roller element, mm