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Theoretical and experimental study on gear-coupling contact and loads considering misalignment, torque, and friction influences

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ABSTRACT

A new analytic model addresses the tooth contact and induced loads of gear couplings that are affected by misalignment, torque, and friction. The contact model accounts for Hertzian, bending, and shear deformations of coupling teeth considering crown modifications. For a specified torque and shaft misalignment, the model calculates the number of teeth in contact, tooth load, stiffness, stress, deformation, and safety factors. The tooth load distribution around the circumference compares well with high fidelity finite-element/contact-mechanics analyses. Simulation time with the analytic model is orders of magnitude less. Using the local contact characteristics, the model computes coupling loads that are primarily caused by the disrupted tooth contact and sliding friction caused by axial motions. This analytic model was validated by experiments. The load amplitude depends on the misalignment, torque, and friction. At low torque, coupling motion was induced by the eccentricity between the hub and sleeve even with nearly perfect alignment. This eccentricity was caused by its self-weight. When torque was larger than a threshold, the motion amplitude was greatly reduced. This torque threshold was analytically derived and validated by experiments.

1. Introduction

Gear couplings are a common machine component used extensively in a wide range of applications including aerospace, manufacturing, automotive, and wind power. Aside from transmitting the driving torque, crowned-tooth gear couplings accommodate some axial motion and angular misalignment between the two connecting shafts. An important aspect of gear couplings is the existence of forces and moments that are transmitted to the driveline when misaligned. Amplitudes of these loads have been reported to be between 12% and 16% of the drive torque for crowned- and straight-tooth couplings [1]. These forces can increase other component loads in the driveline and could lead to high vibration.

The National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL) operates two multi-megawatt wind-energy-specific dynamometers. These dynamometers offer a unique opportunity to perform measurements of coupling performance. Gear couplings used in the NWTC's 5-MW dynamometer testing facility are key components that accommodate angular misalignment and transmit torque from the dynamometer gearbox to the device under test during operation. Coupling-induced loads are ultimately reacted by both the device under test and the dynamometer gearbox, contributing to the

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Nomenclature

A	Arc of gear tooth contact
b	Backlash
C	Single pair tooth stiffness
E	Young's modulus
F	Facewidth
f_c	Half tooth facewidth in contact
f_d	Distance from the tooth center to the contact point
F_c	Contact length of a single tooth
F_d	Distance between tooth center and contact point for a tooth
F_i	Maximum distance between tooth center and contact point
i_d	Design misalignment angle
L_s	Coupling shaft length
$M^{y'}, M^{z'}$	Total bending moments of a coupling around y' and z' axis
$M_d^{y''}, M_d^{z''}$	Single tooth bending moments around y'' and z'' axis
$M_s^{y'}, M_s^{z'}$	Total bending moments of a coupling around y' and z' axis at sensors
$M_t^{y''}, M_t^{z''}$	Total bending moments of a coupling around y'' and z'' axis
N	Number of teeth
$N_{c,d}$	Number of teeth in contact at the sleeve bottom
$N_{c,s}$	Number of teeth in contact at the sleeve sides
N_d	Normal tooth load to the coupling surface
N_s	Number of slices along the facewidth
P	Diametral pitch
P_d	Individual normal tooth load
P_d^s	Load on a single tooth slice along the facewidth
P_i	Maximum normal tooth load
P_i'	Load per unit length
P_t	Total mean normal tooth load
P_t'	Mean normal tooth load
q	Load sharing ratio (number of teeth in contact)
R	Pitch radius
R_c	Hub root crown radius at pitch diameter
R_d	Distance from the hub center to the contact area in the z' direction
R_F	Hub face crown radius (normal plane)
S_{c2}	Design sleeve circular space width
S_{c2}^*	Sleeve circular space width at the contact point
T	Transmitted torque
T_m	Restoring torque
t_{c1}, t_{c2}	Hub and sleeve tooth circular thickness
t_{c1}^*	Hub tooth circular thickness at the contact point
W_c	Coupling weight
W_d	Axial load that balances a coupling tooth
W_{sh}	Coupling shaft weight
w_{sh}	Coupling shaft weight per unit length
Y_1, Y_2	Hub and sleeve tooth AGMA form factor
Z_1, Z_2	Hub and sleeve elasticity factor
z_o	Maximum tooth separation
z_e	Elastic tooth deformation
α	Tooth position angle offset
β	Misalignment direction
ζ	Misalignment angle
ξ	Jam angle
δ_b	Tooth backlash
δ_d	Normal tooth deformation
Δ_c	Accessible tooth root clearance
Δ_r	Design tooth root clearance
γ	Tilt angle
Γ	$cos(\xi)$
ϕ	Normal pressure angle