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PAPER

Development of a systematic instrumentation methodology for continuous torque measurement in high-capacity shafts

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Abstract

This paper presents the development of a systematic instrumentation methodology for continuous torque measurement in high-capacity shafts, based on the application of strain gauges. Within the proposed methodology, systematically derived solutions to the most important challenges in the development of instrumented shafts for torque measurement are presented, including the determination of optimal strain gauge locations, their arrangement and number, as well as the configuration of their connection into Wheatstone bridges. The main objective of the proposed methodology is to achieve high sensitivity and accuracy of torque measurement while simultaneously neutralizing parasitic effects in the output signal of the Wheatstone bridge. In addition, the model-based calibration procedure of the measurement system and an inverse torque determination algorithm based on the output signal of the Wheatstone bridge are presented. The developed methodology was tested on a finite element method (FEM) model of a high-capacity wind turbine shaft under various loading conditions, considering the combined effects of torque (to be measured), bending moments, as well as axial and transverse forces. The obtained results demonstrate that the developed methodology enables high numerical consistency in torque determination, with deviations between the prescribed torque in the FEM model and the torque obtained by inverse determination being less than 0.04%. Thus, it is confirmed that the proposed methodology can be successfully applied in the development of high-capacity instrumented shafts intended for continuous torque measurement.

1. Introduction

Shafts are fundamental machine elements that serve to transmit torque and rotational motion between different components of mechanical systems. Their primary function is to ensure reliable power transmission with minimal losses and deformations, while they often must withstand combined loads, including bending, axial, and transverse forces, thereby making them key elements in the design of complex mechanical systems [1–3].

High-capacity shafts are key mechanical components in systems where large torsional moments are transmitted and the requirements for reliable operation are extremely high. Such shafts are predominantly used in the energy sector, in hydroelectric plants and wind turbines, for the transmission of high torque from the generator or turbine rotor to further transmission stages; in shipbuilding, for ship propellers, where they transmit torque and combined loads resulting from the propulsion system and hydrodynamic forces; in heavy industry and transport, for industrial machinery, heavy mobile equipment, and transportation systems, where high-value torques are transmitted, etc [4–9].

The specific characteristics of high-capacity shafts stem from their design and operational requirements. Such shafts must transmit large torsional moments without loss of strength or the occurrence of deformations that could compromise system functionality. In addition to torsional loading, they are