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In-situ Measurement of Stresses in Carburized Gears via Neutron Diffraction

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

The total stresses in a mating gear pair arise from two sources: 1) externally induced stresses associated with the transmission of power, and 2) residual stresses associated with the heat treatment and machining of the tooth profiles. The stresses due to power transmission are the result of complex normal and shearing forces that develop during the meshing sequence. The total stress from these two sources contributes to the life of a gear.

This paper presents the results of research directed at measuring the total stress in a pair of statically loaded and carburized spur gears. Measurements were made to examine the change in total stress as a function of externally applied load and depth below the surface. The measurements were made using the new Neutron Residual Stress Mapping Facility (NRSF2) instrument at Oak Ridge National Laboratory. A Static Load Application Device (SLAD) was developed to load the gear pair while mounted on the NRSF2 instrument.

Neutron diffraction methods are non-destructive and involve measuring the inter-atomic spacing (d -spacing) of atoms in the crystal lattice using diffractometers that measure the position of a diffraction peak. The measured position is converted to d -spacing using Bragg's Law. The change in d -spacing between stressed and unstressed states allows the determination of strains and consequently the stresses.

Computation of strains using neutron diffraction methods requires that the lattice spacing in the strain-free condition (d_0) be known. The determination of d_0 for a carburized material is not trivial due to carbon, phase and microstructure gradients that exist near the surface. These gradients require that a different value of d_0 be known at each measurement location. The paper includes a summary of various methods that are used to determine d_0 and a discussion of their applicability to carburized gears. The possibility of determining d_0 using ψ -tilt methods is discussed and results are presented for d_0 variation through the carburized layer determined using the $\sin^2\psi$ method.

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Introduction

The total stress in an operating gear is comprised of two types: 1) externally induced stresses associated with the transmission of power, and 2) residual stresses associated with the heat treatment and machining of the tooth profiles. It is the combined effect of these two stress types that contributes to the life of a gear.

Stresses in metallic components can be measured using X-ray and neutron diffraction methods. Historically, these methods have been used to measure only residual stresses. X-ray and neutron diffraction methods involve measuring the interplanar spacing (d-spacing) of atoms in the crystal lattice using diffractometers that measure the position of the diffraction maxima which is converted to d-spacing using Bragg's Law. The measured d-spacing is the average value for a group of grains suitably oriented within an irradiated surface area or volume. The change in d-spacing between stressed and unstressed states allows the determination of strains and consequently stresses.

In recent years there has been interest in using neutron diffraction methods to measure the *in-situ* stresses in operating equipment. It is hypothesized that the penetrating feature of neutrons will allow the measurement of operating stresses inside mechanical components – something that would be totally impossible by X-ray methods. A specific goal of this research was to determine the degree to which neutron diffraction can be used to measure the total stress in meshed carburized gears that are under static load. Considering statically loaded but meshed gears as a first step would allow the effects of the near-surface chemistry, phases, and microstructures to be isolated from dynamically induced phenomena.

Neutron diffraction

Neutron diffraction is an experimental method used to study the structure of a crystalline materials. Neutron diffraction instruments include a source

capable of generating a stream of neutrons called a beam. This beam is directed at a sample and the intensity of the scattered neutrons is measured using detectors. Variations of the intensity at different angular positions around the sample provide information about the crystal structure of the sample. There are two primary types of neutron sources: 1) nuclear reactors and 2) spallation sources. The research presented in this report was conducted using the Neutron Residual Stress Facility (NRSF2) instrument that receives neutrons from the High Flux Isotope Reactor (HFIR). HFIR is located at the Oak Ridge National Laboratory in Oak Ridge, TN.

Figure 1 presents a schematic of the NRSF2 instrument that traces the neutron beam from the reactor to the six position sensitive detectors (PSDs). The beam leaving the reactor core contains many wavelengths and a deformable Si crystal monochromator is used to obtain one of six possible wavelengths. A wavelength of 1.54 Angstroms associated with the Si 422 plane was used for most of this research.

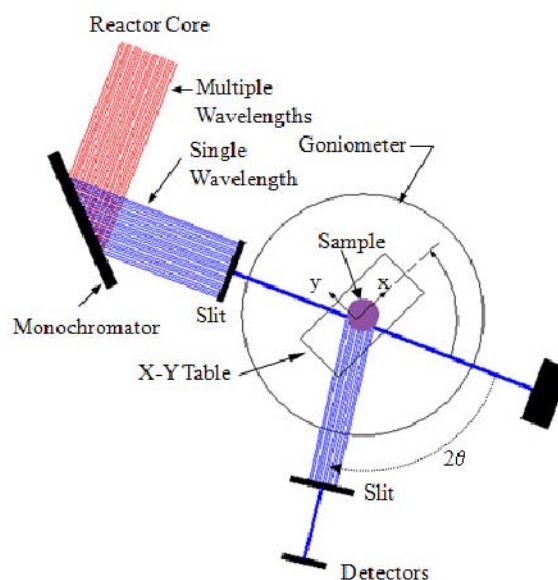


Figure 1. NRSF2 neutron beam schematic

The single wavelength beam leaving the monochromator passes through a snout containing slits. The