



AGMA Technical Paper

Metallurgical Investigation of “Tiger Stripes” on a Carburized High Speed Pinion

By M. Li, Lufkin Industries,
P. Terry, P. Terry and Associates
and R. Eckert, Northwest
Laboratories, Inc.

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March Li, Lufkin Industries, Phil Terry, P. Terry and Associates and R. Eckert,
Northwest Laboratories, Inc.

[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

“Tiger stripes” on a high speed pinion made of a carburized SAE 9310 steel were investigated. The stripes were on lines of action on the load side of the teeth coinciding with different angular positions of the gear mesh. Scanning Electron Microscopy (SEM) of the affected areas showed fused metal particles, with a diameter of 1-3 microns, and gas pockets. The morphology of the damage was typical of electric discharge damage shown in ANSI/AGMA 1010-E95. This indicates that the stripes were in fact electric discharge damage. Microhardness surveys on a metallurgical transverse section of a tooth showed a hardness loss due to the discharge, with load side surface hardness even lower than 58 HRC. The cause of the “tiger stripes” and potential damage to the gear tooth were analyzed.

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American Gear Manufacturers Association
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Introduction

There are lots of gear failure modes depending on the material and related strengthening/hardening processing, working condition (power, speed and load) and environment (temperature, lubrication, corrosion, etc.). It is important to identify the failure mode in order to take necessary measures to mitigate it or to prevent it from occurring.

Among the various failure modes, electric discharge is a common one. It is caused by electric arc discharge across the oil film between mating gear teeth. This discharge may produce temperature high enough to locally melt the gear tooth surface [1]. Electric discharge also causes bearing failures. It was reported [2] that electric discharge pits initiated spalling on a bearing, which created vibration and overheating, leading to fatigue failure of the bearing.

The electric current typically originates from electric motors especially variable frequency drives (VFD), sources of rapidly switching electric currents such as electric clutches, or accumulation of static charge and subsequent discharge. Accordingly, it can be prevented by providing adequate electrical insulation or grounding.

To the unaided eye, a surface damaged by electric discharge appears as an arc burn similar to a spot weld. The density of the spots on the affected surface increases with the increase of the electric current intensity. On a microscopic level, small hemispherical craters can be observed. The edges of the crater are smooth and they may be surrounded by burned or fused metal in the form of rounded particles that were once molten.

ANSI/AGMA 1010-E95 includes some macro- and micrographs showing the morphology of this failure mode. However, it does not mention any other surface appearance or property change. This paper introduces a specific appearance of electric discharge – “Tiger Stripes”, on a high speed pinion made of carburized SAE 9310 steel. Morphology characterization was performed by means of scanning electron microscopy (SEM). The hardness profile across the carburized case depth was measured with a microhardness tester to reveal the damage due to electric discharge.

Application, chemistry, and material tensile properties

The application is a speed increaser gearbox with a 4.735:1 ratio driven by an 1800 rpm VFD electric motor and driving a centrifugal compressor. The high speed pinion has 34 teeth and a normal diametral pitch of 4.

A sample of material was cut from the pinion shaft and analyzed using a mass spectrometer. The results of the analysis are shown in Table 1 along with ranges specified for SAE 9310 steel. It shows that the carbon content is a little high, but all other elements are within the specification.

Two tensile test specimens were prepared from the pinion shaft and the measured mechanical properties are shown in Table 2.

The manufacturing records show that the surface hardness of the pinion teeth is 59-60 HRC with 10% retained austenite and dispersed carbides.

Table 1. Chemistry of the sample, wt.%

Chemistry	C	Si	Mn	Cr	Mo	Ni	S	P
Sample	0.14	0.26	0.66	1.32	0.12	3.28	0.011	0.007
SAE 9310	0.07 0.13	0.15 0.35	0.40 0.70	1.00 1.45	0.08 0.15	2.95 3.55	0.040 max	0.030 max