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## **AGMA Technical Paper**

# **Gear Design Optimization for Low Contact Temperature of a High-Speed, Non-lubricated Spur Gear Pair**

By C.H. Wink and N.S. Mantri,  
Eaton Corporation – Vehicle  
Group

# **Gear Design Optimization for Low Contact Temperature of a High-Speed, Non-lubricated Spur Gear Pair**

**Carlos H. Wink and Nandkishor S. Mantri, Eaton Corporation – Vehicle Group**

[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**

This paper presents a gear design optimization approach that was applied to reduce both tooth contact temperature and noise excitation of a high-speed spur gear pair running without lubricant. The optimum gear design search was done using the RMC (Run Many Cases) program from The Ohio State University. Over 480 thousand possible gear designs were considered, which were narrowed down to the 31 best candidates based on low contact temperature and low transmission error. The best gear design was selected considering, also, its manufacturability. The selected optimum gear design was compared to an existing gear set using LDP (Load Distribution Program) from The Ohio State University. Tooth contact temperature was calculated for both designs using dry a steel-on-steel coefficient of friction. Predicted contact temperature correlated well with results observed on dynamometer tests with the existing gear set. Predictions with the optimized design showed a 48% contact temperature reduction and a 79% noise excitation reduction. The low contact temperature of the optimized design will significantly contribute to preventing tooth surface damage under no lubricant operating conditions.

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# Gear Design Optimization for Low Contact Temperature of a High-Speed, Non-lubricated Spur Gear Pair

Carlos H. Wink and Nandkishor S. Mantri, Eaton Corporation – Vehicle Group

## Introduction

Eliminating lubricant in geared systems is both cost saving and environmentally sound, but poses some technical challenges. Metal-to-metal contact of tooth surfaces sliding and rolling against each other under contact pressure causes high tooth temperature, which may result in material microstructure changes. Tooth surfaces can severely wear away, and even deform plastically. Tooth sliding velocity and contact pressure can be reduced by changing the gear design. However, such design changes may adversely affect gear dynamics and noise that are critical parameters of high speed gears. This paper presents a gear design optimization approach that was applied to reduce both tooth contact temperature and noise excitation of a high-speed spur gear pair running without lubricant. After defining upper and lower boundaries of the main design parameters, and the problem constraints, an exhaustive search within the feasible design region was done using the RMC (Run Many Cases) program from The Ohio State University [1]. Over 480 thousands possible gear designs were considered, which were narrowed down to 31 optimum candidates based on low tooth contact temperature and low transmission error. Each one of those designs was critically analyzed in terms of manufacturability. The selected optimum gear design was compared to an existing gear set using LDP (Load Distribution Program) from The Ohio State University [2], which was also used to optimize micro-geometry modification of profile and lead. Tooth contact temperature was calculated by LDP for both the existing design and the optimum design, and with a dry steel-on-steel coefficient of friction. A good correlation between predicted tooth contact temperature of the existing gear set and test results was observed. A 48% reduction of tooth contact temperature and a 79% reduction of transmission error were achieved with the optimized gear design. The low contact temperature of the optimized design can significantly contribute to preventing tooth surface damage under no lubricant operating conditions.

## Tooth contact temperature

Conjugate action of gear teeth in mesh consists primarily of sliding and rolling motions. At the pitch line sliding velocity is zero. However, sliding velocity increases when the conjugated teeth contact line travels away from the pitch line in both directions. Contact pressure of gear teeth in mesh also changes along the line of action [3]. Heat is generated by sliding friction of teeth surfaces. The temperature distribution is proportional to the distribution of contact pressure and sliding velocity. The instantaneous (or flash) temperature of tooth contact along the line of action is calculated by Blok's contact temperature theory [4]. The contact temperature is the sum of maximum flash temperature along the line of action and the tooth temperature, which is the temperature of the tooth surface before it enters the contact zone [4].

The maximum contact temperature is obtained by equation 1.

$$\theta_{B \max} = \theta_M + \theta_{fl \max} \quad (1)$$

where

$\theta_M$  is tooth temperature, °C;

$\theta_{fl \max}$  is maximum flash temperature along the line-of-action, which is calculated by Blok's equation.

$$\theta_{fl(i)} = 31.62 K \mu_{m(i)} \frac{X_{\Gamma(i)} w_n}{\left(b_{H(i)}\right)^{0.5}} \frac{\left|v_{r1(i)} - v_{r2(i)}\right|}{B_{M1} \left(v_{r1(i)}\right)^{0.5} + B_{M2} \left(v_{r2(i)}\right)^{0.5}} \quad (2)$$