Applied Thermal Engineering 99 (2016) 528–536

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Analysis of bulk temperature field and flash temperature for locomotive traction gear

Ying Shi [a,*], Yu-peng Yao [b], Ji-you Fei [b]

[a] School of Mechanical Engineering, Dalian Jiaotong University, Dalian 116028, China
[b] School of Electric Multiple Units Engineering, Dalian Jiaotong University, Dalian 116028, China

HIGHLIGHTS

- The maximum temperature of the gear tooth surface appears near the addendum.
- Steady temperature of the meshing point whose friction heat flux is minimum is lowest.
- Theoretical value of the transient temperature is calculated by Blok criterion.
- Simulation result of the transient temperature rise is lower than the theoretical value.
- Transient temperature rise obtained by the finite element method is more accurate.

ARTICLE INFO

Article history:
Received 2 April 2015
Accepted 19 January 2016
Available online 28 January 2016

Keywords:
Bulk temperature
Flash temperature
Simulation analysis
Blok flash temperature criterion

ABSTRACT

Sliding velocity variation for gear meshing surface was researched based on theories of gear tribology, heat transfer and Hertz contact, and a model of contact stress considering friction force was derived. The model design process culminated in a comparison of theoretical values and simulated values. Heat flux of friction for different meshing positions and the convective heat transfer coefficient at gear tooth surface and tooth face were initially calculated accurately. The finite element method was then adopted to establish the gear bulk temperature field model and, after the steady state temperature field of the locomotive traction gear was obtained, the distribution law of the steady-state temperature for the gear teeth was analyzed. Transient thermal analysis on the gear was implemented utilizing the steady-state thermal analysis to obtain the transient temperature field of the locomotive traction gear. Applying the Blok flash temperature criterion, theoretical value of the transient temperature rise for the gear tooth surface was calculated. Comparison of the simulation values and the theoretical values for the transient temperature rise indicated that the theoretical values were higher than the simulation values as the Blok flash temperature criterion considers the heat conduction only in the direction vertical to the tooth surface and disregards heat conduction in other directions. The simulation results were then concluded to be superior in practicality and accuracy.

1. Introduction

Gear transmission is widely applied in manufacturing, transportation, metallurgy, chemical industry, pharmacy and aerospace etc. as it retains advantages for smooth transmission, high efficiency, and a compact structure. Locomotive traction gear transmission characterized by high speed and heavy load capacity is increasingly crucial in the railway development process. Locomotive traction gear produces significant heat in the transmission process, forming uneven temperature fields, inducing critical effects on transmission efficiency, dynamic performance, anti-scuffing capacity, bearing capacity, and thermal deformation of gear system [1].

The temperature field of meshing gear consists of two parts: the bulk temperature of gear and transient temperature (flash temperature) of gear surface. Researchers have analyzed the temperature field of gear in theory, experiment and simulation. Changenet et al. researched the relationship of power loss and the automobile transmission gearbox system temperature considering friction heat for gear teeth and rolling bearings [2]. Taburdagitan and Akkok researched key problems of the finite element method and analyzed the transient temperature rise of spur gear [3].

Ebubekir and Ozdemir applied the neural network method to calculate gear tooth surface temperature and the influence of lubricating oil viscosity on the friction coefficient on the tooth surface temperature [4]. Hohn and Klaus researched immersion depth effects

* Corresponding author. Tel.: +86 15904250274; fax: 86041184106314.
E-mail address: shiying1980@163.com (Y. Shi).

http://dx.doi.org/10.1016/j.applthermaleng.2016.01.093

of dip lubricated gear on power loss, bulk temperature and scuffing load carrying capacity utilizing the test method [5]. Results indicated that gear transmission is more easily scuffed with the increase of bulk temperature caused by the reduction of the immersion oil.

Takahashi et al. compared the bulk temperatures of the injection molding plastic gears by the experiments [6]. Kleemola et al. detected the lubrication conditions on-line using bulk temperature and contact resistance measurements by the experiments, and the mean contact resistance and the bulk temperature at different pitch line velocities oil inlet temperature were researched [7].

There are lots of current domestic and foreign researchesstudies. Most of the applied method is one of the theoretical calculation, test and the simulation analysis. The gear temperature fields obtained by different methods have great differences. The cause of the differences is seldom researched, which limits the application of the research achievement for the gear temperature field. In this paper, the theoretical value of the transient temperature rise for the locomotive traction gear and its simulation value are compared. The cause of the differences is analyzed, which provides a more accurate method to research gear temperature field.

Locomotive traction gear is researched in this paper based on theories of gear tribology and heat transmission. A numerical model is then built with consideration to relative sliding speed and Hertz contact stress of the meshing tooth surface for the locomotive traction gear. The heat transfer coefficient of teeth surface is first calculated and the distribution of the friction heat flux is analyzed. Steady-state temperature field of the locomotive traction gear is obtained using the finite element method, and the transient temperature's distribution on tooth surface in the meshing process is obtained by applying the transient thermal analysis of the locomotive traction gear. According to the BLOK flash temperature criterion, the theoretical value of the tooth surface's transient temperature rise is calculated and the difference between theoretical value and simulation value is discussed.

2. Related theories

2.1. Differential equations and boundary conditions of temperature field analysis

The surface temperature of the gear tooth mechanism is changing in the process of gear transmission according to Blok's theory. The effective range of transient surface temperature, however, is minimal and limited to only a very thin hot surface. Temperature of each point for the gear in steady state is typically assumed as constant as the bulk temperature field of gear teeth is disposed as the steady temperature field. When the gear transmission reaches steady state, the friction heat and cooling heat dissipation of gear also tend to be balanced and the temperature change of all teeth is exactly the same, thus a single tooth is utilized for the temperature field research.

The general form of three-dimensional unsteady heat conduction differential equation is:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) + \dot{\Phi} \tag{1}$$

where T is the temperature of the gear, t is the time, λ is the heat conduction coefficient of material in x, y, z direction, $\dot{\Phi}$ is the generating heat per unit time and volume, ρ is the density of a micro unit, and c is the specific heat of a micro unit.

The heat flux generated by meshing gear friction is imposed on the teeth surface, therefore the unsteady heat conduction differential equation of gear is:

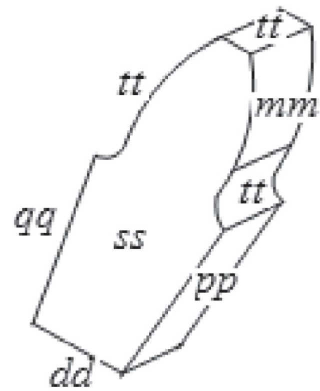

Fig. 1. Single gear tooth model.

$$\rho c \frac{\partial T}{\partial t} = \lambda\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) \tag{2}$$

Determination of the boundary condition of each surface, additionally, is indispensable to solve the temperature field of the gear. Fig. 1 depicts a single gear tooth model.

(1) Friction heat Q and the heat exchange between gear and the surrounding environment on the meshing tooth surface are present; thus, boundary conditions of the meshing tooth surface *mm* are:

$$-\lambda\left(\frac{\partial T}{\partial n}\right) = h_{mm}(T - T_0) + Q \tag{3}$$

(2) The boundary conditions of the addendum, dedendum and non-meshing tooth surface *tt* are:

$$-\lambda\left(\frac{\partial T}{\partial n}\right) = h_{tt}(T - T_0) \tag{4}$$

(3) The boundary conditions of gear face *ss* are:

$$-\lambda\left(\frac{\partial T}{\partial n}\right) = h_{ss}(T - T_0) \tag{5}$$

(4) For interface *dd* of the lower part of the gear tooth:
Because the interface *dd* of the lower part of gear teeth is far from the meshing surface, there is almost no heat conduction in the surface. Therefore it can be considered as adiabatic surface. The boundary conditions of the surface *dd* are:

$$\frac{\partial T}{\partial n} = 0 \tag{6}$$

(5) Tooth sections (surfaces *pp* and *qq*):
Heat conduction appears on the surfaces of tooth sections *pp* and *qq*, with equal heat value of conduction on the two surfaces. The boundary conditions of the surfaces *pp* and *qq* are:

$$T|_{pp} = T|_{qq} \tag{7}$$

$$\left.\frac{\partial T}{\partial n}\right|_{pp} = \left.\frac{\partial T}{\partial n}\right|_{qq} \tag{8}$$

where h_{mm}, h_{tt}, h_{ss} are the heat transfer coefficients in each working area of gear tooth, T_0 is the environment temperature, and n is the exterior normal direction of heat exchange surface.