

Did the Natural Convection Exist in Mechanical Power Transmissions? Theoretical and Experimental Results

by: M. Pasquier, Centre Technique des Industries Mecaniques
(CETIM)

American Gear Manufacturers Association



TECHNICAL PAPER

Did the Natural Convection Exist in Mechanical Power Transmissions? Theoretical and Experimental Results

Michel Pasquier, Centre Technique des Industries Mecaniques (CETIM)

[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 thermal rating of mechanical power transmissions is based on the balance between the power lost in the gear unit and the power exchanged through the surfaces, for a given temperature in the housing.

The exchange of power is performed according the following ways : Conduction, radiation and convection.

Obviously, the radiation is a function of the material of the housing, the coating and the dust which may cover it.

Concerning the convection, it should be distinguish between the natural convection and the forced convection.

The value of the coefficient of heat exchange, by way of convection, strongly influence the value of the total heat exchange coefficient.

The technical reports ISO 14179 parts 1 et 2, give values of total heat exchange coefficient in case of natural convection and forced convection.

Based on the equations of dynamic of fluids and heat, our task is to compare the values of total heat exchange obtained from this theoretical study to the values given in the technical reports. Our theoretical values are supported by experimental results. Did the natural convection exist in mechanical power transmissions?

Copyright © 2000

American Gear Manufacturers Association
1500 King Street, Suite 201
Alexandria, Virginia, 22314

October, 2000

ISBN: 1-55589-767-3

DID THE NATURAL CONVECTION EXIST IN ENCLOSED GEAR DRIVES?

Theoretical and experimental results

M. PASQUIER

Centre Technique des Industries Mécaniques (CETIM) – BP 80067 60304 - SENLIS Cedex – France

1 INTRODUCTION

The thermal rating of enclosed gear drives is based on the balance between the power lost in the gear unit and the power exchanged by the surfaces of the housing for a given service temperature inside the unit.

The exchange of power is performed by the following ways: The conduction, the radiation and the convection.

Obviously, the radiation is a function of the material of the housing, the coating and the dust which may cover it.

Concerning the convection, it must be distinguished between the natural and the forced convection.

The value of the coefficient of exchange by way of convection strongly influence the value of the total heat exchange coefficient.

In the technical reports ISO 14179 parts 1 and 2, it is provided values for the coefficient of exchange in the case of natural convection and in those of forced convection.

On the basis of the equations of dynamic of fluids and the equation of heat, our task is to compare the values of the total heat exchange coefficient obtained with respect to these given in the technical reports.

Did the natural convection exist in enclosed gear drives?

2. FORMULA FOR THE THERMAL RATING OF ENCLOSED GEAR DRIVES

The thermal rating of enclosed gear drives is based on the following equilibrium relationship:

Power lost = Power exchanged

2.1. Power lost

The power lost is calculated for each component of the gear unit: i.e. for the gear wheels, the bearings, the seals,...

The power lost may be load or no load dependant.

It can be written as follows :

$$P_L = P_{LGO} + P_{LG}(F) + P_{LBO} + P_{LB}(F) + P_{LS} + P_{Lg}$$

P_{LGO} : Power lost by the gears (P_{LGO} no load power lost, $P_{LG}(F)$, load dependant power lost) (W)

P_{LBO} : Power lost in the bearings (P_{LBO} no load power lost, $P_{LB}(F)$, load dependant power lost) (W)

P_{LS} : Power lost in the seals (W)

P_{Lg} : Power lost in the auxiliary component GLYCO. (W)

2.2. Power exchanged

The power exchanged is a function of the area of the surface of exchange of the unit, i.e., the area of the housing (A in m^2), the temperature differential between the outside and the inside of the gear unit ΔT in $^{\circ}C$ and obviously the total exchange coefficient k in $W/m^2\ ^{\circ}C$

$$P_Q = A k \Delta T \quad (1)$$

In order to evaluate the thermal power of an enclosed gear drive, it must be assumed a difference of temperature between the inside of

the housing of the gear unit and the ambient temperature. In the Technical Report ISO 14179 part 1 and 2, it is considered an inside temperature in the housing of 95°C and an ambient temperature of 40°C, that means a differential of 55°C.

It is also assumed a value for the coefficient of exchange which is mainly function of the way of convection chosen: natural convection or forced convection.

3. CONVECTION - SIMILITUDE

In order to solve a problem of convection when the density ρ (kg m^{-3}) is assumed to be a constant value, one dispose of two equations : the equation of dynamic and the equation of heat.

If the viscosity μ (Pa s) and the density ρ may be assumed as constant values, the problem of dynamic and the thermal problem split. But, in return, in order to solve the thermal problem, it must be known the field of speed.

Even in this case, the equation of dynamic can not be solved analytically and it must be determined by experiments (numerical and/or actual) to obtain the flow of heat and the other global values.

One is involved to write the values in a non dimensional form, which allows
In one hand to realize experiments on scale models in physical similarity,
On the other hand to generalize the known results from one other experiment to all other different situations.

3.1. Natural convection - similarity

3.1.1. Equation in natural convection. Boussinesq assumption [1]

Let us consider a body in static condition with a uniform temperature T_p surrounded by a fluid immobile far from the body and of a temperature T_0 .

The density of the fluid ρ is a function of the temperature T

i) Equation of dynamic

Let us assume that the dynamic viscosity, μ is not dependant of the temperature T

$$\rho \frac{D\vec{V}}{Dt} = -\text{grad } P + \rho \vec{g} + \mu \left[\Delta \vec{V} + \frac{1}{3} \text{grad}(\text{div } \vec{V}) \right] \quad (2)$$

where :

$$\frac{DV}{Dt} = \frac{\partial V}{\partial t} + u \frac{\partial V}{\partial x} + v \frac{\partial V}{\partial y} + w \frac{\partial V}{\partial z}$$

P is the pressure, (Pa)

g is the gravity (m s^{-2})

$\vec{V}$ has the following boundary conditions: $\vec{V} = 0$ on the wall and far away.

ii) Equation of heat

$$\rho c \frac{DT}{Dt} = \alpha \Delta T \quad (3)$$

where :

$$\frac{DT}{Dt} = \frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z}$$

$T = T_p$ temperature on the wall ($^{\circ}\text{C}$)

$T = T_0$ temperature far away ($^{\circ}\text{C}$)

α is the thermal conductivity of fluid ($\text{W m}^{-1} \text{ } ^{\circ}\text{C}^{-1}$)

c is the specific heat capacity of the fluid at constant pressure ($\text{J kg}^{-1} \text{ } ^{\circ}\text{C}^{-1}$)

If $T_p \neq T_0$ and if it is considered a unit of volume dv , the force which applies on it is the algebraic sum of the force due to the gravity and the pressure force (Archimedes' principle).

If it is assumed that the density varies very little in the range of temperature, it can be written according Boussinesq assumption

$$\rho = \rho_0 [1 - \beta(T - T_0)] \text{ avec } \beta(T - T_0) \ll 1 \quad (4)$$

where :

β , is the coefficient of thermal expansion of the fluid. (K^{-1})

Let us consider $\varepsilon = \beta(T - T_0)$ as a small parameter and find $\vec{V}$ and P as follows :

$$\begin{cases} \vec{V} = \vec{V}_0 + \varepsilon \vec{V}_1 + \varepsilon^2 \vec{V}_2 + \dots \\ P = P_0 + \varepsilon P_1 + \varepsilon^2 P_2 + \dots \end{cases} \quad (5)$$