The influence of temperature on the engagement process of the wet clutches

Zhe Yang*
Jiangsu Automation Research Institute, Jiangsu, 222023, China
yangzhe@jari.cn

Abstract. The wet clutch is an important component in the vehicle transmission system, which has an important influence on the smoothness and rapidity of the vehicle starting and shifting processes. As a friction element, wet clutches are usually troubled by the wear and breakage problems, caused by high temperature. To solve this problem and reveal the operating mechanism, a dynamic model, along the circumferential and axial direction is proposed to describe the engagement process. In addition, a lumped thermal resistance model is established to predict the changing trend of the temperature during the engagement process. Then, with these two models, an integrated model is proposed. From the simulation results, the initial temperature has little effect on the temperature rise of the wet clutch. While, it has an obvious influence on the viscous torque, the higher the temperature is, the smaller the viscous torque is. While, for the asperity torque, it is opposite.

1. Introduction

As the basic executive element of action process of the gearbox, the working characteristics of the wet clutches play an important role for the smoothness and reliability of the vehicle operation. Scholars have conducted a lot of explorations on its working mechanism, and the friction torque generation mechanism and friction during the engagement process. The temperature field, thermal failure and friction characteristics of the components have been studied from various aspects and angles.

When the wet clutches is in a sliding state, its contact interface is in a very complicated working state. From 1970 to 1973, Wu [1-3] used the finite difference method to study the characteristics of the squeeze oil film during the engagement process of the porous annular disc and the rotating porous annular disc. The process of the transition from dynamic pressure lubrication to boundary lubrication is revealed. Subsequently, Ting [4] conducted a modeling study on wet clutches, considering the friction surface roughness and porous surface characteristics. Ting utilizes the poroelastic theory to study the boundary lubrication stage, but the groove effect was not considered. Aiming at this point, EI-Sherbiny [5] used the finite element method to study the influence of the groove type on the working process of the wet clutch. Furthermore, Natsumeda [6] conducted numerical simulations on wet clutches made of paper-based materials, and the models built by them focused on factors such as permeability of friction materials, surface roughness contact, compressibility, centrifugal force, etc. The results obtained are in good agreement with the experimental data.

Through the research on related fields, the working process, friction performance, working principle and other aspects of wet clutches have achieved good results. However, the current research has certain deficiencies on the influence of temperature. To investigate the influence of temperature on the engagement process, this paper proposes an integrated model for the wet clutches, and the simulation results are presented.
2. Dynamic model for the engagement process

The structure of wet friction pair is simplified as follows, shown in Fig. 1. The simplified structure is composed of a piston, a piston cylinder, a pair of steel plates and a friction plate.

\begin{equation}
F_{\text{app}} = (m_0 + m_2) \ddot{x} + (c_0 + c_2) \dot{x} + F_v + F_c
\end{equation}

\begin{equation}
h = h_0 - x
\end{equation}

$F_v$ is the oil film dynamic pressure, it can be described by the following equation.

\begin{equation}
F_v = \int_A \frac{B}{4A} (r^2 - R_c^2) + \frac{3 \eta}{A} \frac{\partial h}{\partial t} (r^2 - R_c^2) + \ln \frac{r}{R_2} \left( \frac{B}{4A} \frac{\partial h}{\partial t} + \frac{3 \eta}{A} \frac{\partial h}{\partial t} \right) \ln R_c - \ln R_o
\end{equation}

\begin{equation}
A = \phi_1 h^3 + 12 \psi d_m
\end{equation}

\begin{equation}
B = \frac{\phi_1 \rho h^3}{5} (3 \omega_1^2 + 4 \omega_1 \omega_2 + 3 \omega_2^2)
\end{equation}

\begin{equation}
\overline{h} = \frac{h}{2} \left[ 1 + erf \left( \frac{h}{\sqrt{2} \sigma} \right) \right] + \frac{\sigma}{\sqrt{2} \pi} e^{-\frac{k^2}{2 \sigma^2}}
\end{equation}

During the engagement process of the wet clutch, when the oil film thickness reaches the same order of magnitude as the surface roughness of the contact surface, the micro-convex body on the contact surface begins to contact and bears a part of normal joint pressure. The contact pressure generates.

\begin{equation}
F_c = \int_A p_c
\end{equation}

\begin{equation}
\left\{ \begin{array}{l}
p_c = K' E' \cdot 4.4086 \times 10^{-5} \cdot (4 - H)^{0.804}, H < 4 \\
p_c = 0, \quad H \geq 4 \end{array} \right.
\end{equation}

\begin{equation}
K' = \frac{8 \sqrt{2}}{15} \pi (N \beta \sigma)^{\frac{1}{2}} \left( \frac{\sigma}{\beta} \right)^{\frac{1}{2}}
\end{equation}

\begin{equation}
\frac{1}{E'} = \frac{1}{E_1} \left( 1 - \frac{v_1^2}{E_1} \right) + \frac{1}{E_2} \left( 1 - \frac{v_2^2}{E_2} \right)
\end{equation}

Equations (1-10) describe the changing trend of wet clutch along the axial direction. While, the rotating condition should also be described. During the entire engagement process, the viscous torque can be described as follows.
3. Lumped thermal resistance model

According to the analysis of the heat dissipation hydraulic system, the components of the hydraulic system are simplified into nodes based on lumped parameters, ignoring material differences, shown in Fig. 2. The nodes include system components and their internal lubricating oil, where: E is the environment; P for the pump; V is the pressure reducing valve; RV is the relief valve; C is the wet friction pair; R is the radiator; F is the fuel tank.

For components and lubricants in nodes, the internal thermal resistance of the object is ignored, the temperature variations can be deduced by the following equation.

\[
\begin{align*}
C_i \frac{dT_i}{dt} &= \Phi_i - K_{i,j} (T_j - T_o) - \sum_j K_{i,j} (T_i - T_e) \\
C_o \frac{dT_o}{dt} &= \Phi_o - K_{o,j} (T_{jo} - T_i) - \sum_j K_{o,j} (T_o - T_{jo})
\end{align*}
\] (16)

Taking the of wet clutch as an example, the Equation (16) can be deduced into the following equation.
4. Simulation results analysis
With the dynamic model for the engagement process and the lumped thermal resistance model, the engagement process, the rotating condition, and the temperature variation of the wet clutch can be simulated. To investigate the influence of initial temperature on the engagement process, the relative speed between is fixed at 117.8 rad/s and the joint pressure is kept constant at 130 kPa. Other simulation parameters are listed in Table 1.

Table.1 Simulation parameters

| Parameters | Meanings                        | Parameters | Meanings                        |
|------------|---------------------------------|------------|---------------------------------|
| $A_{red}$  | percentage of non grooved area  | $p$        | pressure                        |
| $E$        | elastic modulus                 | $r$        | radius                          |
| $F$        | force                           | $v_s$      | slipping speed                  |
| $I$        | moment of inertia of components | $\Phi_{\text{(e)}}$ | heat source                     |
| $M$        | torque                          | $\Psi$     | permeability of materials       |
| $N$        | asperity density                | $\beta$    | curvature radius of asperity    |
| $R$        | radius of friction disc         | $\mu$      | friction coefficient            |
| $R_H$      | radius of asperity              | $\omega$   | angular speed of components     |
| $T$        | temperature of components       | $\eta$     | coefficient of kinetic viscosity|
| $V$        | volume                          | $c$        | specific heat capacity          |
| $x$        | displacement                    | $\rho$     | density                         |
| $h$        | clearance                       | $\sigma$   | the RMS surface roughness       |
| $\phi$     | flow factors                    | $\nu$      | Poisson's ratio                 |
| $d_m$      | thickness of surface material    | $\kappa$   | plastic deformation coefficient |
| $m$        | weight                          |            |                                 |

Under three different conditions, the simulation results are shown as follows. From the simulation results, it can be seen that the initial temperature has little effect on the temperature rise of the clutch friction element, which is basically about 12 ℃, as shown in Fig. 3(a). At the beginning of the engagement process, the friction torque decreases obviously with the increase of temperature, which is illustrated in Fig. 3(b). This is because the higher the temperature is, the lower the dynamic viscosity of the lubricating oil is, and the smaller the viscous torque generated under the same working condition, as shown in Fig. 3(c). As the engagement process continues, in the simulation results, the peak value of asperity torque is different at different temperatures and decreases with the increase of temperature, as shown in Fig. 3(d). This phenomenon is caused by the changing of the friction coefficient of the wet clutch under different temperatures.

\[
\begin{align*}
C_c & \frac{dT_c}{dt} = \Phi_c - K_{c,E}(T_c - T_E) - K_{c,F}(T_c - T_F) - K_{c,\omega C}(T_c - T_{\omega C}) \\
C_{\omega C} & \frac{dT_{\omega C}}{dt} = \Phi_{\omega C} - K_{\omega C,E}(T_{\omega C} - T_E) - K_{\omega C,F}(T_{\omega C} - T_F) - K_{\omega C,\omega C}(T_{\omega C} - T_{\omega \omega C}) \\
& - K_{\omega C,\omega C}(T_{\omega C} - T_{\omega C}) \\
\Phi_c &= M_c \Delta \omega = (M_c + M_r) \cdot \Delta \omega
\end{align*}
\]
5. Conclusions

Through the integration of different models, a comprehensive model of wet clutch engagement process was established, including the dynamic model of axial and circumferential motion, the optimized fictionalized coefficient and the thermal resistance model of predicting temperature variation.

Under different conditions, the initial temperature has little effect on the temperature rise of the wet clutch. While, with the increase of the initial temperature, the friction torque decreases obviously, which is caused by the decrease of the dynamic viscosity of the lubricating oil. As for the asperity torque, its peak value increases with the increases of temperature.

References

[1] Wu H. Squeeze-Film Behavior for Porous Annular Disks [J]. Journal of Lubrication Technology, 1970, 92(4):593-596.
[2] Wu H. The Squeeze Film between Rotating Porous Annular Disks [J]. Wear, 1971, 18:461-469.
[3] Wu H. An Analysis of the Engagement of Wet Clutch Plates [J]. Wear, 1973, 24:23-33.
[4] Ting L L. Engagement Behavior of Lubricated Porous Annular Disks [J]. Wear, 1975, 34:159-182.
[5] EI-Sherbiny M G, Newcomb T P. Numerical Simulation of The Engagement Characteristics of a Wet Clutch, Oil-immersed Brakes and Clutches [D]. New York, 1977.
[6] Natsumeda S, Miyoshi T. Numerical Simulation of Engagement of Paper Based Wet Clutch Facing [J]. Journal of Tribology, 1994, 116(2):232-237.