Temperature Field in Torque Converter Clutch

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Abstract. Torque Converter Clutch (TCC) works longer than ever before because of slipping technology intervention. The friction coefficient of TCC friction plate will change with temperature. In order to get the dynamic friction coefficient and also ensure the friction plate temperature not too high, TCC temperature was calculated on simulation model. First, the work of friction plate slipping was calculated when TCC working; Second, the three-dimensional fluid structure interaction model of Torque Converter (TC) was built basing on CFX, then the temperature field of TC and the Variation of TCC friction plate were simulated; Last, the friction coefficient of TCC friction plate was corrected with its temperature change in real time, and also a temperature threshold was set in order to protect TCC.

Introduction

TCC works in slipping or combination conditions through controlling the Import and export oil pressure [1]. Torque was transmitted by the friction between the owners, driven friction plate of TCC, so the friction coefficient has great influence on the torque transmission. TCC will produce a large amount of heat during the combination process, the contact area, coefficient and contact oil pressure of TCC friction plate vary with temperature. The influence of temperature must be considerate when calculating the torque TCC transmitted and then correcting the TCC friction plate coefficient. TCC friction plate temperature rise will lead to a sharp increase in the amount of wear of friction materials; the friction plate wear problem has serious impact on Automatic Transmission.

TCC works longer hours than ever before because of slipping technology intervention [2]. The cost of TCC friction plate increases greatly when wearing. The TCC friction plate temperature threshold was set In order to get over temperature protection in the premise of ensuring the control performance of the TCC controlled system.

TCC Friction Work

Working process of TCC

In general, TCC working process can be divided into three stages [3]: oil-filled stage, slipping stage and locking stage. TCC working process was showed in Figure1.

At oil-filled stage, oil filled with TCC, and the initial pressure was established, as showed in Figure1 t_0-t_1 stage. At this stage, TCC transmitted certain torque because of back pressure, but the TCC transmitted torque was very small owing to the effects of vibration and shock.

At slipping stage, as showed in Figure1 t_1-t_m stage, the torque TCC transmitted became more and more until coupling conditions. When TC worked in the coupling conditions, the torque amplifying function of TC will be lost.

At locking stage, as showed in Figure1 t_m-t_2 stage, TC lost the torque amplifying function, in order to improve the efficiency, TCC should be locked.

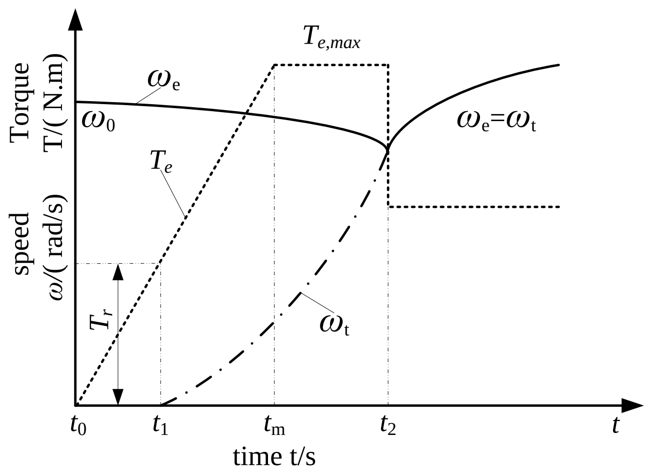


Figure1 TCC working process

Calculation Formula

In the process of TCC slipping until combined, its owners, driven friction plates speed experiences ranging from difference to the same, the work when TCC owners, driven friction plates mutually moving is the friction work. Friction work is not only the size of the heat load evaluation, but also for the lockup clutch transient temperature field analysis, temperature model, friction temperature forecast basis. In the process of TCC slipping until combined, its owners, driven friction plates speed experiences ranging from difference to the same.

Friction work can be calculated by Equation (1)

$$W_f = \int_0^t T(\omega_e - \omega_t)dt \tag{1}$$

Where ω_e= engine speed, equal to impeller speed; ω_t = turbine speed.

Friction work is in form of heat flux [4] on the surface of the TCC friction plate, heat flux can be calculated by Equation (2)

$$q_{(r,t)} = \mu R_m u_p(t)\Delta\omega \tag{2}$$

Where μ= friction coefficient; R_m = equivalent radius of TCC friction plate; $u_p(t)$ = TCC oil pressure; and $\Delta\omega$ = speed difference between TCC owner friction plate speed and driven friction plate speed, also called slipping speed.

Calculation Results

Through the test, the desired values Equation (1) and Equation (2) showed were obtained; heat fluxes TCC working at different throttle was showed in Figure2

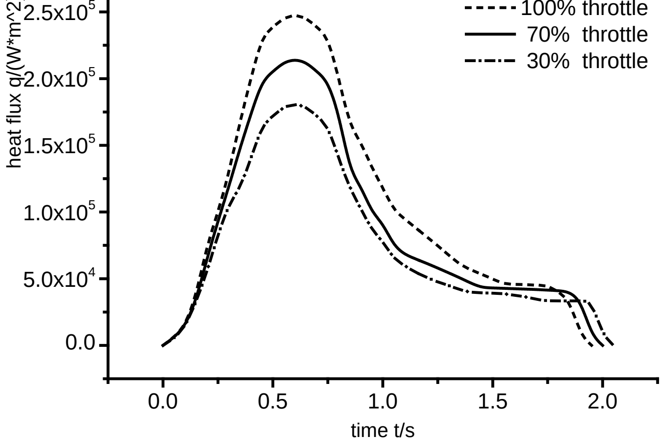


Figure2 Heat fluxes TCC working at different throttle

From Figure2, it seemed that heat fluxes TCC working at different throttle had substantially the same trends. In the initial stage, heat flux increased rapidly because of rapidly rising TCC oil pressure and larger slipping speed; In the second stage, TCC oil pressure varied slowly, slipping speed decreases gradually, so heat flux decreases gradually; In the last stage, TC worked at coupling conditions, then TCC closed, slipping speed closed to zero, finally TCC work stopped, heat flux trended to zero.

TCC Three-dimensional model

Structure of TC

Structure of TC was showed in Figure3. TC contains impeller (2), stator (3), torsional damper (5), oil pressure (6), TC shell (7), TCC (8) and turbine. TCC was controlled by oil pressure. When TCC work, oil pressure flowed [5] from the right of turbine, pushed turbine and TCC on the left, and then TCC combined. At the same time, part of oil playing the role of lubrication and heat transfer flowed to clearance of TCC friction plate through the clearance between TC shell and the turbine top, and last flowed to lubricating oil way. When TCC separated, oil pressure from turbine shaft entrance pushed TCC and turbine toward the right, flowed to lubricating oil way through the clearance between TC shell and the turbine top.

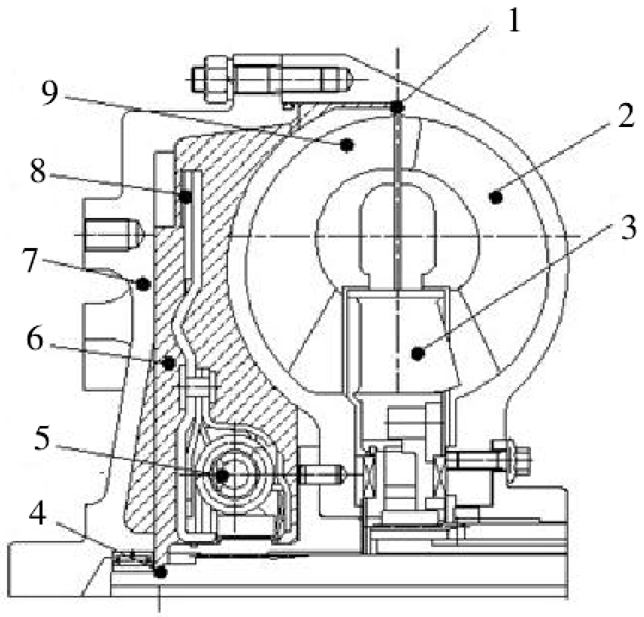


Figure3 Structure of Torque Converter

Two-dimensional model

TC structure can be seen as a three-dimensional axisymmetric rotating structure [6], so TCC model can be seen as along the symmetry axis of rotation. Two-dimensional model was showed in Figure4

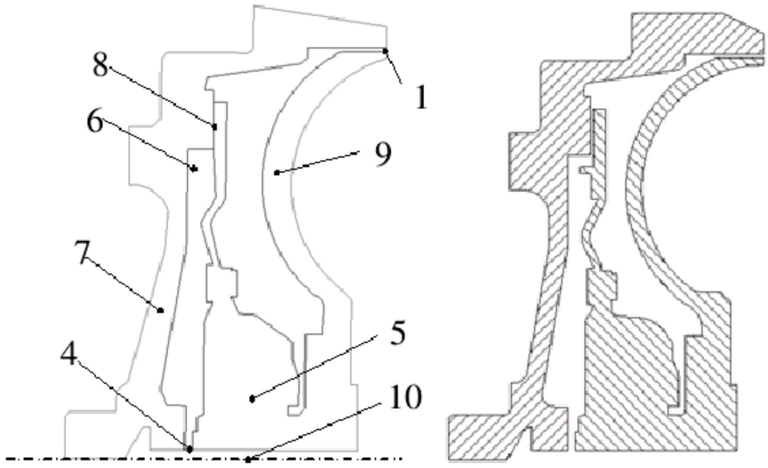


Figure4 TCC Two-dimensional model

In order to reduce memory, save computing time, TCC three-dimensional model can be built as two-dimensional rotating 15 degrees and on both sides to set periodic boundary conditions.

TCC three-dimensional model

TCC three-dimensional model was showed in Figure5

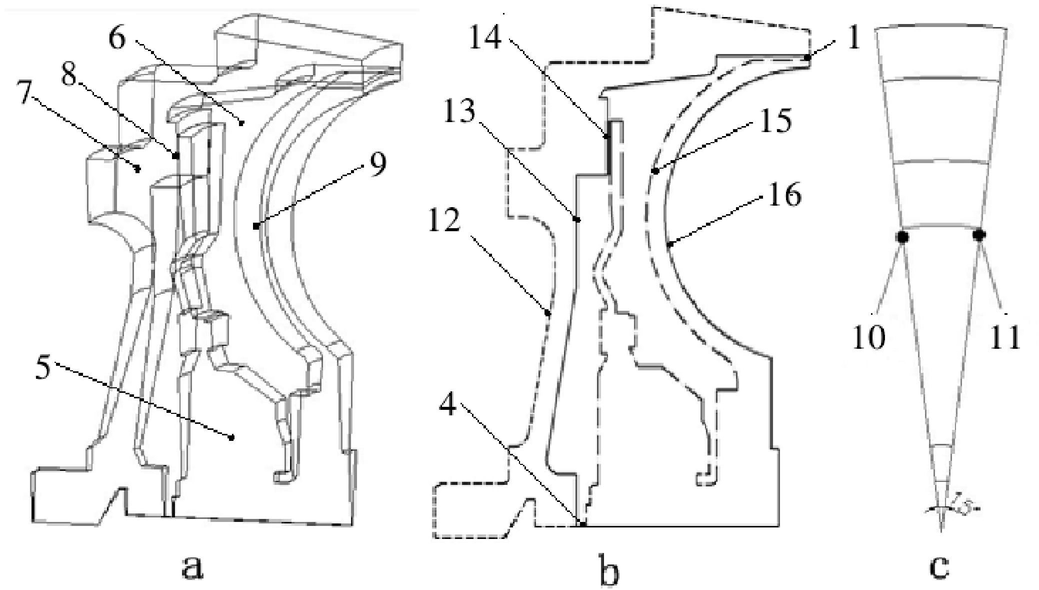


Figure5 TCC three-dimensional model

TC was simplified to TC shell (7), oil (6), the internal solid including torsional damper (5), TCC (8) and turbine (9). The impeller and stator were ignored because of staying away from TCC. Oil When TCC working flowed from the entrance (1) to exit (4), through the groove of TCC friction plate. Referring to Figure5, the two-dimensional model (Figure4) rotated 15 degrees along the axis of symmetry (10) and then became the three-dimensional model, on both sides to set periodic boundary conditions. The main plane of rotation (11) and the accessory plane of rotation (12) were set to periodic boundary. The three-dimensional model contained the outer surface of TC shell (13), the coupling surface between TC shell and oil (14), TCC friction plate area (15), the coupling surface between oil and the inner solid (16).

Simplified oil grooves

TCC friction surface alternately opens a deep recess of about 0.3-0.5mm called friction plate oil groove[7]. The role of friction plate oil groove increase the friction coefficient and heat dissipation, Scour debris. TCC works in a closed environment oiled. Through the friction plate oil groove, the oil takes heat away relying on the centrifugal force; it's greatly improved the life of the TCC. The form of oil groove is very important for the friction plates. At high speed, small kinematic viscosity conditions, the oil groove help reduce drag torque; In contrast, at low speed, large kinematic viscosity conditions, the oil groove is not conducive to reduce drag torque. The oil groove has big effect on disc surface heat dissipation; different forms of oil groove have different cooling effect. In Three-dimensional fluid-structure coupling model based CFX, the oil needs to work as a whole, but the actual work is by lining the oil groove. To simplify the model, the oil groove is simplified to a gap about 0.2(mm), different oil groove has different heat flux.

Temperature field of TCC

The range of TC oil temperature is wide, typically 40℃-140℃. Low viscosity is favorable to the transmission efficiency and the sensitivity of TCC control systems; But, in order to meet the lubrication requirements of gears and bearings, Reduce the hydraulic control system and pump leakage, the viscosity of the working oil should not be too low, based on the above considerations, the oil optimum operating temperature is about 80℃.

There were two kinds of temperature field: steady temperature field and transient temperature field. Steady temperature field is to verify whether temperature can achieve balance and equilibrium or not at certain slipping speed, oil pressure and calculate the maximum temperature; transient temperature field is to get TCC temperature varying with time.

Steady temperature field

Steady temperature field when oil temperature at 80℃ was showed in Figure6

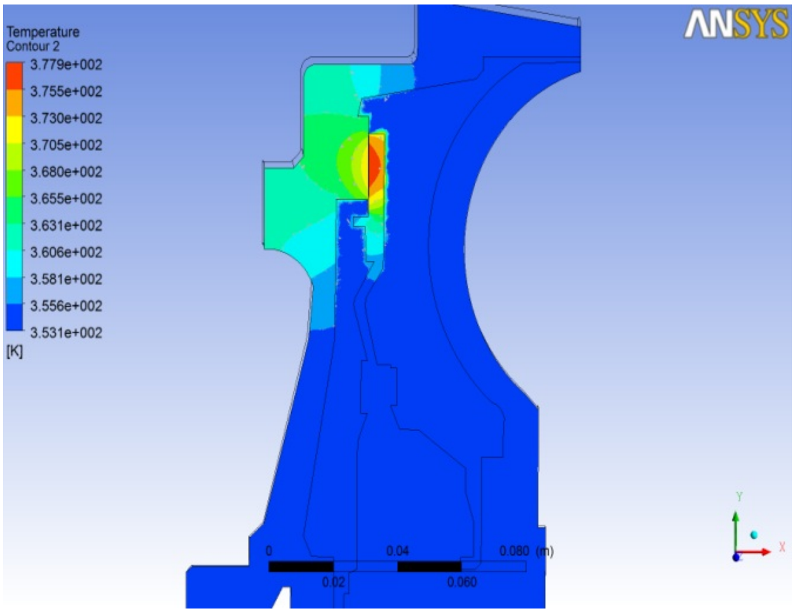
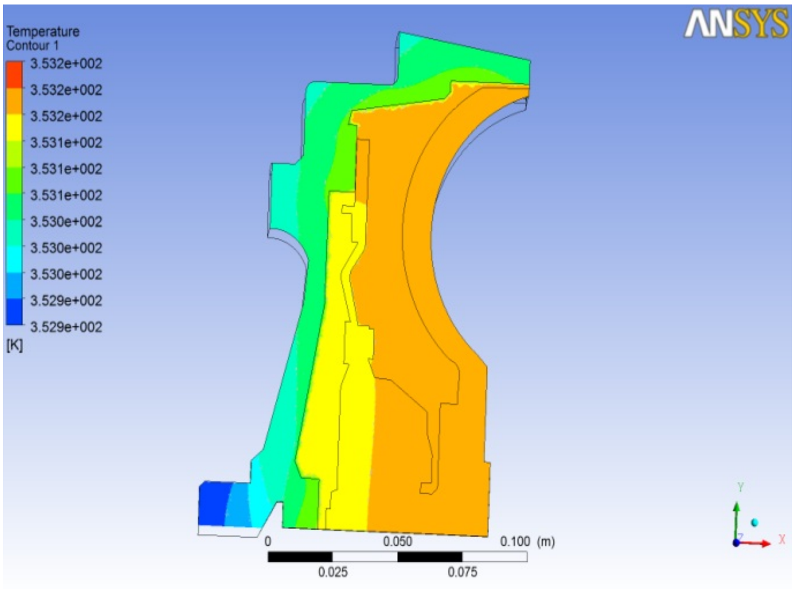


Figure6 Steady temperature field

From Figure6, it seemed that TCC can reach equilibrium temperature field, Most of the heat generated by the TCC friction plate was transmitted by TC shell because of its strong convective heat transfer capacity.

Transient temperature field

The purpose of transient temperature field analysis was to study the TCC friction plate temperature with its working process. In order to compare TCC friction plate trends at different temperature, two temperature fields were simulation when oil temperature at 80℃, 100℃. According to the heat flux calculation results of figure 2, the initial field of transient temperature field

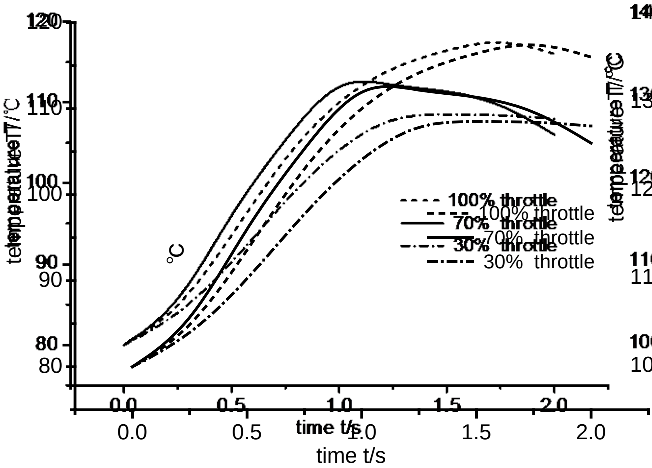


was showed in Figure7

Figure7 the initial field of transient temperature field

From Figure7, it seemed that parts of TCC were passing temperature each other, TCC fluid - solid coupling transfer model can accurately calculate the temperature field.

When oil temperature was at 80℃, the temperature curve of TCC friction plate center was showed in Figure8, when oil temperature was at 100℃, the temperature curve of TCC friction plate center was showed in Figure9



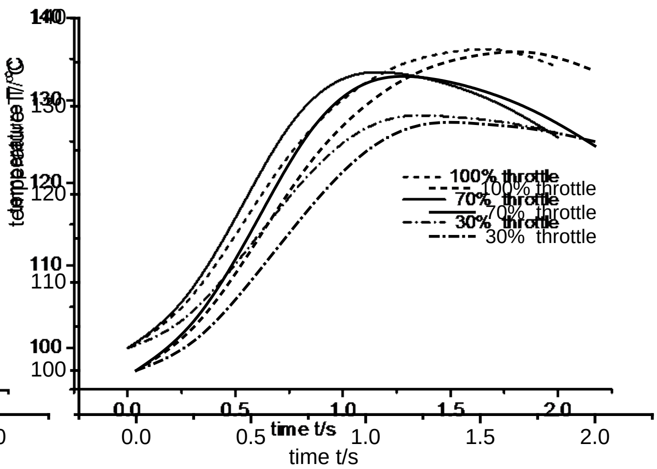


Figure8 the temperature curve of TCC friction plate center   Figure9 the temperature curve of TCC friction plate center

From Figure8, it seemed that TCC friction plate temperature began to rise rapidly, and then slowly rise, in line with the actual situation.

From Figure9, it seemed that TCC friction plate temperature had the same variation tendency at different oil temperature; The greater the throttle opening, the higher TCC friction plate temperature, TCC friction plate temperature are also the highest temperature of about 35℃; but this temperature had exceeded the maximum 125℃, TCC should stop working.

When oil temperature was at 80℃, the TCC temperature field at a certain moment was showed in Figure10

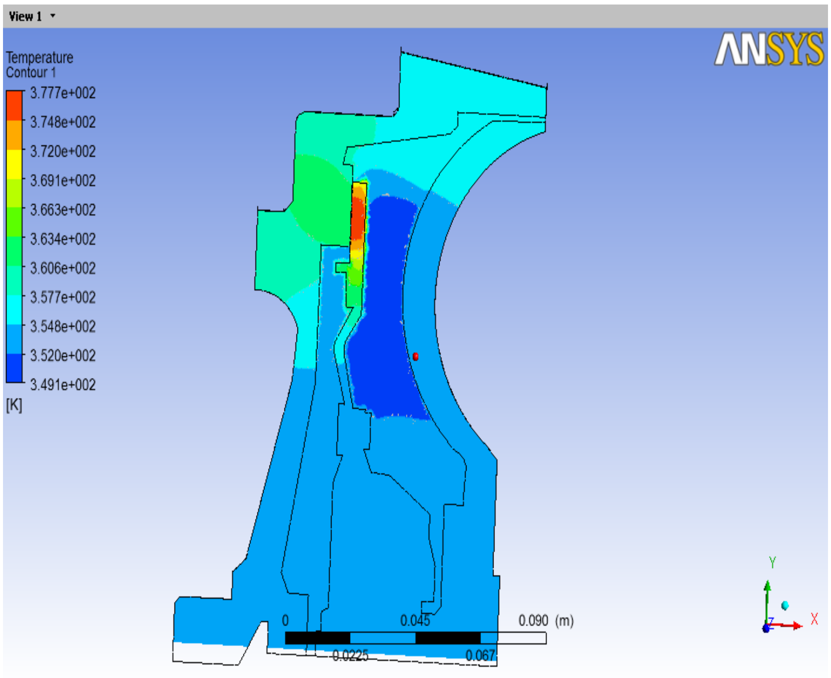


Figure10 the TCC temperature field at a certain moment

From Figure10, it seemed that the highest temperature of TCC was in the middle position of TCC friction plate. Heat was mostly taken by the TC shell instead of oil cooling. When TCC friction plate temperature exceeded its maximum (threshold), TCC control must be cancel to avoid damaging the TCC, and extending its life.

Summary

In order to get the dynamic friction coefficient and also ensure the friction plate temperature not too high, the TCC temperature was calculated on simulation model. The simulations reveal that TCC friction plate temperature rises quickly because of TCCs drive and driven plate large speed difference and long sliding time, its maximum temperature rise is about 35℃. At a certain oil temperature, TCC friction plate temperature had exceeded the maximum (threshold) temperature, TCC should stop working.

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