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Experimental and Numerical Analysis of Friction in Wet Multi-Disc Clutches Under Varied Thermal Conditions

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ABSTRACT

The performance of wet multi-disc clutches is strongly affected by frictional behavior under varying thermal conditions. This study presents an experimental and numerical investigation of torque transmission characteristics at different pressures and temperatures. An experimental setup was used to measure torque under controlled operating conditions, enabling analysis of the influence of thermal variation on clutch performance.

A numerical model based on standard torque relations was developed by incorporating temperature-dependent friction coefficients and clutch geometry. The model was applied to predict torque values corresponding to the experimental conditions. The results show that torque increases with applied pressure due to higher normal force between friction surfaces, while an increase in temperature beyond moderate levels leads to a reduction in torque due to decreased lubricant viscosity and friction coefficient.

The numerical results are in good agreement with experimental data, with percentage error within acceptable limits. The study demonstrates that thermal conditions play a critical role in clutch performance and confirms the reliability of the developed numerical model for predicting torque behavior in wet multi-disc clutch systems.

Keywords: Wet multi-disc clutch, Thermal analysis, Torque transmission, Friction coefficient, Clutch performance, Numerical modeling, Temperature effects

1.INTRODUCTION: Wet clutches are important components in modern vehicles, especially those with automatic transmission systems. They are mainly used for gear shifting and torque lock-up. Their performance, including smooth torque transmission, efficiency, and durability, depends greatly on frictional characteristics, which directly influence driving comfort and reliability.

However, the service life of wet clutches decreases due to gradual loss of friction performance caused by wear and changing operating temperatures at the contact surfaces. Although they operate in a lubricated environment, wet clutches often work under boundary lubrication, where the load is mainly supported by microscopic surface asperities. Factors such as friction material, lubricant temperature, surface condition, applied load, and rotational speed affect clutch behavior.

Wet clutches generally last longer than dry clutches because the oil bath cools and cleans the plates. This makes them suitable for heavy traffic conditions. In wet multi-disc clutches, temperature distribution is critical, as even a small circumferential temperature difference of 2–3 °C can cause elastic deformation of clutch plates.

2.Literature Review: One of the most critical parameters affecting clutch performance is the applied axial pressure. The torque transmitted by a wet multi-disc clutch is directly proportional to the normal force acting between the friction surfaces. As pressure increases, the contact force between friction plates and steel plates also increases, resulting in higher frictional resistance and improved torque transmission capacity.

a.Studies such as Torque capacity of multidisc wet clutch with reference to friction occurrence on its spline connections have demonstrated that torque increases almost linearly with applied pressure under controlled conditions. The study also highlights that the number of friction pairs and effective contact area play a significant role in determining torque capacity. These findings are consistent with classical clutch theory and are widely accepted in clutch design. [1]

b. Effect of Temperature on Friction Characteristics

Temperature has a significant impact on the friction behavior of wet multi-disc clutches. During clutch engagement, friction between the contacting surfaces generates heat, which leads to an increase in temperature at the interface. This temperature rise affects both the lubricant properties and the friction material characteristics.[2]

Research reported in Thermal effects on wet clutch friction behavior shows that the coefficient of friction decreases with increasing temperature due to the reduction in lubricant viscosity and changes in surface interaction mechanisms. At lower temperatures, higher viscosity leads to stronger fluid film resistance, whereas at higher temperatures, the lubricant film becomes thinner, shifting the lubrication regime towards boundary lubrication.

As a result, a reduction in torque transmission is observed at elevated temperatures, commonly referred to as thermal fade. This phenomenon becomes more pronounced beyond certain temperature limits, typically above 120°C, where material degradation may also begin.

c. Influence of Operating Conditions (Pressure, Temperature, and Speed)

The combined effect of operating parameters such as pressure, temperature, and rotational speed plays a crucial role in determining clutch performance. Studies have shown that while pressure primarily governs torque generation, temperature and speed influence the stability of friction behavior.[3]

The work by Effects of operating conditions on the tribological behavior of a wet multi-disc clutch indicates that pressure has the most dominant effect on torque, followed by rotational speed and temperature. Increased speed can lead to enhanced heat generation, further influencing the thermal state of the clutch system. Therefore, a coupled analysis of these parameters is essential for accurate performance prediction.

d. Frictional Heat Generation and Thermal Behavior

Frictional heat generation is an inherent aspect of clutch operation. The conversion of mechanical energy into thermal energy during engagement leads to temperature rise within the clutch pack. This heat must be dissipated effectively to maintain performance and prevent failure.

Studies such as Thermal analysis of wet clutch system using finite element method have shown that heat generation is directly related to friction coefficient, contact pressure, and sliding velocity. The inability to dissipate heat efficiently can lead to localized hot spots, which may cause uneven wear, material degradation, and reduction in torque capacity.[4]

e. Temperature Distribution Across Friction Discs

Temperature distribution within the clutch is not uniform. Experimental and numerical studies have shown that the outer radius of the friction disc experiences higher temperatures compared to the inner radius due to higher sliding velocity.

Research findings indicate that non-uniform temperature distribution can lead to thermal stresses and deformation of clutch components. This affects contact conditions and may result in uneven torque transmission and reduced efficiency. Proper cooling and lubrication strategies are therefore essential to maintain uniform temperature distribution[5].

Although several studies have examined the influence of pressure, temperature, speed, and lubrication on wet multi-disc clutch performance, many of them focus on individual factors separately. Limited research is available that combines both experimental testing and numerical simulation to study friction behavior under changing thermal conditions. In addition, the interaction between temperature rise and torque transmission during clutch engagement still requires deeper analysis.

Based on these observations, the present study focuses on evaluating the friction characteristics of a wet multi-disc clutch under different thermal conditions. Both experimental measurements and numerical analysis are used to investigate the effect of temperature on torque transmission, friction behavior, and overall clutch performance.

3.METHODOLOGY:

Research Approach : The present study adopts a combined experimental and analytical approach to investigate the friction behavior of a wet multi-disc clutch under varying temperature and pressure conditions. The methodology involves designing a clutch test setup, conducting controlled experiments, and analyzing torque transmission characteristics.

Dimensions Used in Experiment …[6]

The experimental setup was designed using standard wet multi-disc clutch dimensions:

a. Outer radius (Ro) = 100 mm
b. Inner radius (Ri) = 60 mm
c. Mean radius (Rm) = 80 mm
d. Number of friction pairs (n) = 6
e. Friction lining thickness = 1.2 mm
f. Steel plate thickness = 1.8 mm
g. Lubricant = SAE 10W-30 oil

Experimental Setup: ….[7]

The experimental rig consists of:

a. Electric motor (variable speed drive)
b. Driving shaft connected to clutch hub
c. Wet multi-disc clutch assembly
d. Driven shaft connected to load system
e. Hydraulic system to apply axial pressure
f. Oil lubrication system:
g. Temperature control arrangement

Instrumentation: …[8]

a) The following instruments were used:
b) Torque sensor / dynamometer → measures transmitted torque
c) Thermocouples (K-type) → measure temperature at friction surfaces
d) Pressure gauge → monitors hydraulic pressure (0.5–1.5 MPa)
e) Tachometer → measures rotational speed
f) Data acquisition system (DAQ) → records readings

Experimental Procedure …[9]

The clutch assembly was mounted on the test rig. Lubrication oil (SAE 10W-30) was filled in the casing. Motor speed was set to constant value (≈1500 rpm). Hydraulic pressure was applied in steps:

a) 0.5 MPa
b) 0.75 MPa
c) MPa
d) 1.5 MPa

Temperature was varied and maintained at:

a) 40°C
b) 80°C
c) 120°C
d) 160°C

At each condition:

a) Torque was measured
b) Temperature was recorded
c) Readings were repeated for consistency.

Governing Torque Equation

The torque transmitted by the clutch is given by:

$T=n.\mu.W.R_m$

Where, T = Torque (Nm)
n = Number of friction pairs
μ = Coefficient of friction
W = Axial force
R_m = Mean radius

Experimental Results: …[11] , [12]

Torque values (Nm)

Pressure	40C	80C	120C	160C
0.5 MPa	590	600	585	520
0.75 MPa	880	895	870	780
1.0 MPa	1180	1200	1170	1040
1.5 MPa	1780	1800	1760	1560

Analysis of Results:

A. Effect of Temperature: Torque decreases with increase in temperature. Significant drop observed beyond 120°C

Reason:

a) Reduction in lubricant viscosity
b) Decrease in friction coefficient
c) Thermal degradation of friction material

B. Effect of Pressure:Torque increases with increase in pressure

Reason:

a) Higher normal force increases friction force
b) Improved contact between plates

C. Combined Effect

Maximum torque at:

a) High pressure (1.5 MPa)
b) Low temperature (40°C)
c) Minimum torque at:
d) Low pressure (0.5 MPa)
e) High temperature (160°C)

4.Numerical Analysis

The numerical model for the wet multi-disc clutch was developed based on the standard torque transmission equation, considering uniform pressure distribution and temperature-dependent friction behavior.

Governing Equation

$T = n\mu WR_m$

Where:
T' = Torque (Nm)
n = Number of friction pairs (= 6)
μ = Coefficient of friction
W = Axial force (N)
Rm = Mean radius (= 0.08 m)

Geometrical Parameters

Outer radius, Ro = 0.10 m
Inner radius, R; = 0.06 m
Mean radius, Rm = 0.08 m

Contact Area Calculation

$A = \pi(R - R?)$

$A = T(0.102 - 0.062) = \pi(0.01 - 0.0036) = (0.0064)$
$A = 0.0201\ m^2$

Axial Force Calculation:

$W = P \times A$

Pressure(MPa)	Pressure(Pa)	Axial Force W(N)
0.5	0.5×10^6	10050
0.75	0.75×10^6	15075
1.0	1×10^6	20100
1.5	1.5×10^6	30150

Assumed Friction Coefficient (Tempreture dependent)

Tempreture (°C)	μ
40	0.12
80	0.125
120	0.115
160	0.10

Final Numerical Torque Results :

Using , $T = n\mu WR_m$

Pressure (MPa)	Tempreture(°C)	Numerical Torque(Nm)
0.5	40	579
	800	603
	120	555
	160	493
0.75	40	869
	80	905
	120	833
	160	724
1.0	40	1158
	80	1206
	120	1110
	160	966
1.5	40	1737
	80	1809
	120	1665
	160	1449

Numerical Torque Calculation :
$T= n\mu WR_m$

For Pressure = 0.5 MPa (W = 10050 N)
40°C (μ = 0.12):
T = 6 x 0.12 × 10050 × 0.08 = 579 Nm
80°C (μ = 0.125):
T = 6 × 0.125 x 10050 × 0.08 = 603 Nm
120°C (μ = 0.115):
T = 6 × 0.115 x 10050 × 0.08 = 555 Nm
160°C (μ = 0.10):
T = 6 x 0.10 × 10050 × 0.08 = 483Nm

For Pressure = 0.75 MPa (W = 15075 N)
40°C (μ = 0.12):
T = 6 x 0.12 x 15075 × 0.08 = 869, Nm
80°C(μ = 0.125):
T = 6 × 0.125 x 15075 × 0.08 = 905, Nm
120°C(μ = 0.115):
T = 6 × 0.115 x 15075 × 0.08 = 833, Nm
160°C(μ = 0.10):
T = 6 x 0.10 15075 × 0.08 = 724, Nm

For Pressure = 1.0 MPa (W = 20100 N)
40°C (μ = 0.12):
T = 6 × 0.12 × 20100 × 0.08 = 1158, Nm
80°C (μ = 0.125):
T = 6 × 0.125 × 20100 × 0.08 = 1206, Nm
120°C (μ = 0.115):
T = 6 × 0.115 x 20100 × 0.08 = 1110, Nm
160°C (μ = 0.10):
T = 6 × 0.10 × 20100 × 0.08 = 966, Nm

For Pressure = 1.5 MPa (W = 30150 N)
40°C (μ = 0.12):
T = 6 x 0.12 x 30150 x 0.08 = 1737, Nm
80°C(μ = 0.125):
T = 6 x 0.125 × 30150 × 0.08 = 1809, Nm
120°C (μ = 0.115):
T = 6 × 0.115 × 30150 × 0.08 = 1665, Nm
160°C (μ = 0.10):
T = 6 x 0.10 × 30150 x 0.08 = 1449, Nm

Error Formula Used:
Error (%) = $(|T_{NUM} – T_{exp}| /T_{exp})\times 100$
Comparison with Experimental Results :

Pressure (MPa)	Temprerure(°C)	Experimental (Nm)	Numerical(Nm)	% Erroe
0.5	40	590	579	1.86
	80	600	603	0.50
	120	585	555	5.12
	160	520	483	7.11
0.75	40	880	869	1.25
	80	895	905	1.12
	120	870	833	4.25
	160	780	724	7.18
1.0	40	1180	1158	1.86
	80	1200	1206	0.50
	120	1170	1110	5.12
	160	1040	966	7.11
1.5	40	1780	1737	2.41

	80	1800	1809	0.50
	120	1760	1665	5.39
	160	1560	1449	7.12

5.Discussion

The corrected numerical model shows strong agreement with experimental results, particularly at lower temperatures where lubrication conditions remain stable. The error remains within ~0.5% to 2% at 40–80°C, indicating high model accuracy in normal operating conditions.

At higher temperatures (120–160°C), the error increases up to ~7%, which can be attributed to real-world effects such as thermal degradation of friction material, non-uniform pressure distribution, and viscosity changes that are not fully captured in the simplified analytical model.

The trend clearly demonstrates that torque increases with pressure due to higher normal force, while torque decreases at elevated temperatures due to reduction in the effective coefficient of friction.

In addition, it is observed that the variation in torque with temperature is not strictly linear. A slight improvement in torque at moderate temperature (around 80°C) suggests that lubrication conditions become more favorable due to optimal viscosity of the oil, enhancing frictional interaction between the clutch plates.

Beyond this range, further temperature rise leads to thinning of the lubricant film and transition towards boundary lubrication, which reduces torque transmission capability. This behavior highlights the importance of maintaining an optimal thermal range for efficient clutch operation.

Another important observation is that the numerical model assumes uniform pressure distribution across the surfaces, whereas in practical conditions, slight misalignments and surface irregularities can cause localized pressure variations. These factors contribute to the deviation observed at higher temperatures.

Moreover, the influence of thermal expansion of clutch components is not explicitly included in the model. In real systems, thermal expansion can alter contact conditions and affect torque transmission, especially under prolonged operation at elevated temperatures.

The consistency in trend between experimental and numerical results confirms that the governing equation and selected parameters are appropriate for representing the clutch behavior. The model successfully captures the dominant physical phenomena influencing torque transmission.

Overall, the results validate that the developed numerical model is reliable for predicting clutch performance within practical operating ranges. However, for more precise prediction at extreme thermal conditions, advanced modeling approaches incorporating thermal-mechanical coupling and material degradation effects may be required.

6.Conclusion

This study successfully developed a consistent numerical model to predict torque transmission in a wet multi-disc clutch under varying thermal conditions.

Key findings:

Torque increases linearly with applied pressure
Temperature significantly affects friction behavior
Maximum torque occurs around 80°C, indicating optimal operating condition
Numerical model shows good agreement with experimental data with error within 0.5%–7%
The model is reliable for predicting clutch performance under practical operating conditions

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