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MODELING AND SIMULATION OF DRY FRICTION CLUTCH CONSIDERING DYNAMIC PERFORMANCE

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ABSTRACT
Power transmission is an effective mechanical mechanism for changing vehicle speeds from the first speed to the next speed as it requires vehicles to increase the speed while driving. Therefore, clutches are crucial in ensuring effective power transmission and speed change in vehicles. In a conventional transmission, gears are changed by using a clutch to separate and connect the movement and change between gears. It depends entirely on the friction generated between two plates to transmit power, so it is made of a suitable material to perform this task. In this paper , the types of clutches used in vehicles were displayed, transferring motion through friction. The materials from which these clutches are made were also displayed, which depend mainly on friction and the value of the coefficient of friction. MATLAB was used to build a mathematical model to study the clutch's performance. Also, the performance of the clutch was studied under some appropriate parameters.

KEYWORDS
Modeling, Simulation, MATLAB, Dry friction clutch, and Dynamic performance.

INTRODUCTION
Clutches are an essential component to ensure effective power transmission and speed change. Clutches are divided into mechanical clutches and hydraulic clutches. Mechanical clutches are used in vehicles, and various types include dry clutches for small vehicles requiring low power to move, and wet clutches, which are immersed in oil for cooling due to the generated heat during power transmission. Wet clutches are used in trucks, transport vehicles, and those requiring high power to move. Clutches can also be classified as single-disc clutches and multi-disc clutches.

Clutches are manufactured from suitable materials to perform their intended function. The clutch must meet certain conditions: it should not cause vibration during starting and ensure the safe and smooth transfer of engine torque without slipping. It should have high friction resistance, be easy to operate, and provide high starting torque. Clutches play a crucial role in ensuring effective power transmission and speed change in vehicles. Understanding how they work and the factors affecting their performance helps maintain the safety and performance of the vehicle.

Friction Materials of Clutches

Numerous industrial machines' drivelines are safeguarded by overload clutches. They can be divided roughly into two groups: those that rely on the friction between a metal object and a friction material, and those that depend on the sliding or rolling contact of metal objects, frequently utilizing the ratchet principle. Since rigid clutch discs are more affordable and have a specially adjusted cushion deflection, they are becoming more common in modern transmissions with dual mass flywheels (DMF).

Friction clutch plates can be made of steel, pressed asbestos, bronze, cork, SF-BU, Kevlar49, sintered iron, aluminum 6061, or grey cast iron. There are two types of clutches: single plate clutches for light duty vehicles and multi-plate clutches for heavy duty vehicles with multiple friction plates and steel plate assembly. Taimin Gong et.al, [1], study, a copper-based friction material was slid against alloy steel in a ring-on-ring braking simulator, a wear map constructed from measured wear rates was partitioned into ultra-mild, mild and severe wear regimes, and the dominant wear mechanisms that control these wear regimes. A load range of 1.0~3.0 MPa, a braking speed range of 6.7~20.1 m/s, and a moment of inertia of 0.1 kg m^2 were used to measure wear rates.

When the wear regime was ultra-mild (W<10−6 mm^3/J), plastic deformation and micro-plowing were the main wear mechanisms of the friction material based on copper. The mild wear regime showed signs of abrasive wear, while the severe wear regime (W>10−5 mm^3/J) showed signs of delamination and abrasive wear.

Dhokey et. Al, [2], fabricate green compacts with a height to diameter ratio of 0.95–1.0 and a compacting pressure of 438 MPa were created using copper powder (≤10 µm) and α-SiC particles ranging in size from 25–37 µm. Physical, mechanical, and microstructural analyses were performed on the compacts that were sintered at 860 °C in a nitrogen atmosphere. In order to measure the mass loss from wear over a 2500 m sliding distance, a wear test was carried out on a Pin-On-Disc machine using an experimental plan consisting of four loads (15 N, 25 N, 45 N, and 65 N) and four sliding speeds (0.6, 1.2, 1.8, and 2.4 m/s). The dimensional equation in terms of wear rate parameter, interface, was stated using the wear rate (mm3/m) computed for each load and sliding speed combination.

Fernandes et. Al, [3], mention that clutch samples tested in three distinct field conditions were characterized in order to examine the impact of a developed friction film on clutch system performance. Lab simulations were conducted on the identified wear mechanisms. A pin-on-disc tribometer was used to test cast iron and a commercial truck friction material for this. Standard procedures and cleaning of the counter-face's wear track were used to conduct ribological tests. At constant sliding speeds of 2.05 ms^{-1} and 3.27 ms^{-1}, the normal load ranged from 200 N to 450 N for both lab test conditions.

Gowthama Rajan et. Al, [4], by using modeling and analysis techniques, developed a robust and efficient analytical methodology for the design of mechanical single plate clutches. The structural, thermal, and wear behavior characteristics of a single plate clutch using nanocoated materials like ZrO_2 and TiO_2 were examined. All during the working state, the coefficient of friction is relatively high. An appreciable increase in energy absorption occurs for a short while. When standing, compressive pressures from high-pressure plates are applied. Zirconium oxide is the most appropriate

material in terms of strain and deformation properties. Contact between the friction surfaces should not require the application of any external force to the clutch. A readily repairable clutch should be incorporated into its design. A heat-dissipating mechanism at the contact surface is necessary for the clutch to operate properly.

Vishnu Vardhan et. Al, [5], design and analysis of a friction clutch plate made of various materials are the main objectives of the work. One of the most important parts of an automobile is the single plate clutch. Using CATIA, a single plate clutch model with predetermined dimensions was created and examined. Materials chosen for this investigation included ceramics, aluminum alloy, and E glass epoxy. The clutch has undergone static, dynamic, and thermal analysis to ascertain stresses and deformations. In comparison to the other materials, the results show that the Aluminum Alloy 6061 has performed well in static, dynamic, and thermal analysis. Based on the observations, aluminum alloy 6061 may be the most appropriate material in the circumstances.

Dry Clutches

power, and they use two or more dry friction interfaces to control the pressure between the friction pairs to adjust the angular speed. Vehicles with dry clutches use them to slip for extended periods when launching and shifting gears, [6]. Due to the relative slipping motion between the contact friction pairs, there is a significant amount of frictional heat generated during their interaction, causing the temperature to rise sharply.

An essential consideration in the design and operation of dry clutches is the thermal behavior under harsh operating circumstances, [7]. While the contact counterparts are conductors that dissipate frictional heat, the friction disc is an insulator with a high frictional coefficient. Uneven temperature distribution in the friction pairs and high temperatures in the interior of the friction disc are caused by mild heat convection that takes place between the friction pairs and in the air gap in the clutch housing.

However, the pressure exerted on the friction disc is controlled by inflexible mechanisms, which leads to an uneven distribution of pressure. Adverse effects like surface cracks and permanent deformation can result from localized high pressures and temperatures. Hot spots may form at the contact regions if the slipping speed surpasses the critical value, thereby causing instability in the coupled thermomechanical behavior, [8].

Koranteng et.al, [9], evaluated an improved Cu-based friction material made using powder metallurgy technique to determine its wear rate and friction properties using a universal material tester. Examined how operating temperatures and sliding speeds affected thermal buckling and thermoelastic instability of the friction disc. Additionally, there was no evidence of thermal buckling.

Khamlichi et.al, [10], suggested that a high fiber-to-matrix ratio would be more practical to quickly remove frictional heat if the yarn's thermal properties predominate over the mixtures. To calculate the thermal properties of the clutch facing, we used a homogenization technique for facing morphology. Large variations in clutch-facing performance and temperature distribution were achieved with a moderate variation in the fiber ratio after establishing the dependency relationship between clutch-facing morphology and thermal properties.

Abdullah et.al, [11], established relationships between the amount of energy transferred by convection and the groove area ratio. For various groove ratios, the internal energy variation over time was also depicted. modified the groove area ratio for a dry friction clutch disc and assumed a uniform distribution of the thermal load between the contact surfaces to investigate the impact of radial circumferential grooves on the temperature distribution using a finite element technique. Consideration was given to friction clutches with and without radial circumferential grooves. To assess the maximum temperature and total heat transferred by convection, various groove area ratios were taken into consideration in this work.

Mouffak et.al, [12], manipulated the friction material, the angular velocity, and the pressure applied by the pressure plate to simulate various clutch model variations and analyze the temperature distribution for a single engagement. The clutch facing's material and thermal behavior were examined using models featuring zero, four, and eight grooves. A few crucial elements were shown to reduce the frictional energy caused by convection and conduction for an enhanced lifecycle.

Czél et.al, [13], validated the experimental results by simulating the thermal behavior of a dry ceramic disc and connecting the two separate FE models via changes in the heat partition over time and space. Redesigning the clutch components to maximize thermal energy absorption and promote efficient heat convection would be made easier with the aid of this kind of thermal modeling.

A pad-on-disc type tester was used to assess the friction and wear properties of six different friction materials containing varying amounts of phenolic resins and aramid pulp. They discovered that friction materials reinforced with 10% (by vol.) of aramid pulp performed significantly better in terms of friction stability, regardless of resin type, [14].

Analysis was done on the thermal behavior of clutches using four different friction materials and different groove designs, , [15]. To forecast early failure points and thereby confirm the design's functionality, an accurate temperature map of the clutch must be received. An approximate understanding of the relative thermal performance and suitability of various friction lining materials for commercial, heavy-duty, and racing applications can be obtained by simulating a dry friction clutch disc under maximum loading conditions. By choosing the right material and employing a better-designed grooved pattern, the thermal characteristics can be enhanced.

Antonio Della Gatta, [16], introduced a study that delves into the various models of clutch transmissibility and control strategies for engagement proposed in recent decades. The study provides an overview of modeling dry clutch torque and discusses key factors affecting torque transmission, including temperature, sliding speed, contact pressure, and wear.

Mirsad Trobradovic, [17] presented a research endeavor that scrutinized the engagement process of a single plate dry clutch. The study identified the core parameters affecting this engagement and crafted a mathematical model aimed at mimicking clutch functionality, with a specific focus on the dynamics of the pressure plate. Utilizing the MATLAB/Simulink software package, simulations were

conducted, and to ensure accuracy, the model's outcomes were corroborated against experimental data found in the existing literature.

Clutch Model

This model explains the operation of the clutch which consists of two plates that transmit torque between the engine and transmission. There are two different modes of operation: the first model slipping, where the two plates have differing angular velocities; and the other model locked up, where the two plates rotate together. There are two methods for solving this type of problem:

1. Compute the clutch torque always transmitted, and employ this value directly in the model.
2. Use two different dynamic models and switch between them at the appropriate times.

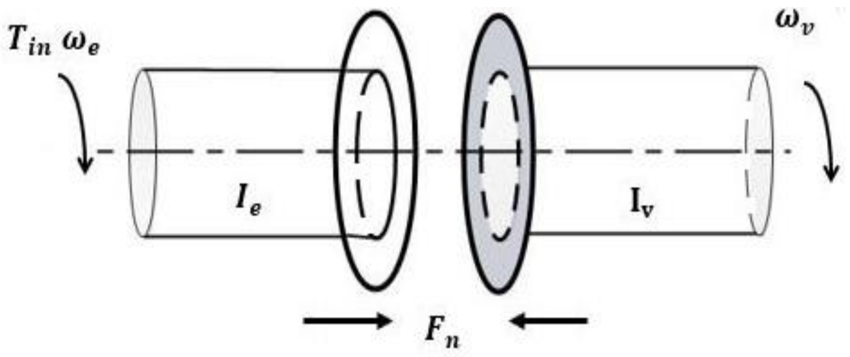

Fig. 1 Clutch Model.

Figure (1) shows the clutch Model.

The torque transmitted when the clutch slips and kicks up demonstrates the following equation [18][19][20]:

$$I_e\dot{\omega}_e = T_{in} - b_e\omega_e - T_{cl} \quad (1)$$

$$I_v\dot{\omega}_v = T_{cl} - b_v\omega_v \quad (2)$$

Where:

T_{in} input (engine) torque

T_{cl} torque transmitted through the clutch.

b_e, b_v damping rates at the engine and transmission/vehicle sides of the clutch

ω_e, ω_v angular speeds of the engine and transmission input shafts

I_e , I_v moments of inertia for the engine and for the transmission/vehicle.

The normal force that is applied to the clutch: -

$$T_{f\,max} = \frac{2}{3}RF_n\,\mu \quad (3)$$

Where:

$T_{f\,max}$ friction torque required of the clutch to maintain lockup.

R equivalent net radius

F_n *the* normal force between friction plates.

μ the coefficients of friction

When the clutch is slipping, the model uses the kinetic coefficient of friction and the full capacity is
available, in the direction that opposes slip.

$$T_{f\,max} = \frac{2}{3}RF_n\,\mu_k \quad (4)$$

Where:

μ_k The kinetic coefficients of friction.

$$T_{cl} = sgn(\omega_e - \omega_v)T_{f\,max} \quad (5)$$

When the clutch is locked, $\omega_e = \omega_v = \omega$ and the system torque acts on the combined inertia as a single unit.

$$T_{cl} = T_f = \frac{I_v T_{in} - (I_v b_e - I_e b_v)\omega}{I_v + I_e} \quad (6)$$

$$T_{f\,max} = \frac{2}{3} R F_n\, \mu_s \quad (7)$$

Where:

μ_s the static coefficients of friction.

The clutch behavior in two states slipping and lock up has been described in Figure (2) which shows the diagram of clutch behavior.

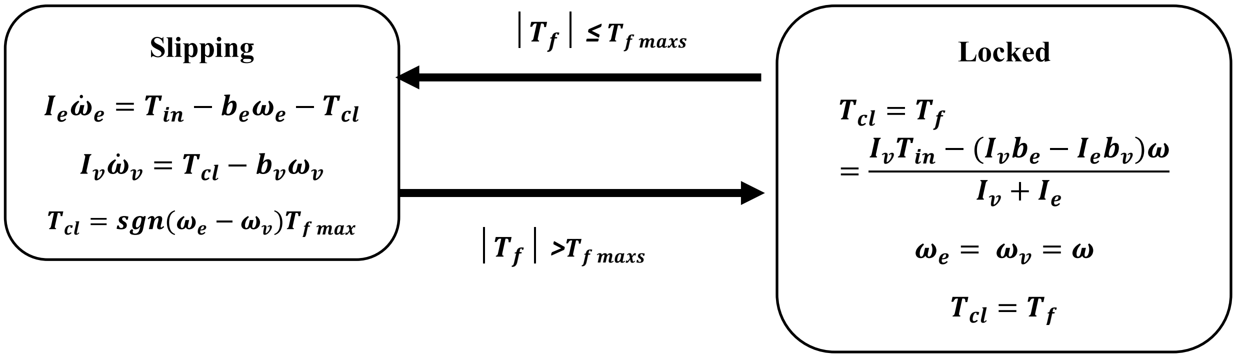

Fig. 2 A state diagram describing the friction mode transitions.

MATLAB has been used to create the clutch model. The model consists of two subsystems, the first model, which simulates the clutch in the slipping state, and the second model simulates the operation of the clutch in the locked-up state. As shown in Figure 3, the model is slipping and locked up state, where there is a difference between the angular speed of the wheels and the angular speed of the engine, but in the case of locking up, the clutch is in a locked state, which is the opposite of the previous state in the previous state, in which both the angular speed of the wheels and the speed are equal Originates from the engine.

Both models were used to study the performance of the clutch in two states by measuring both the angular speed of the wheels and the angular speed originating from the engine. Clutch performance is also measured at different values of normal force F_n.

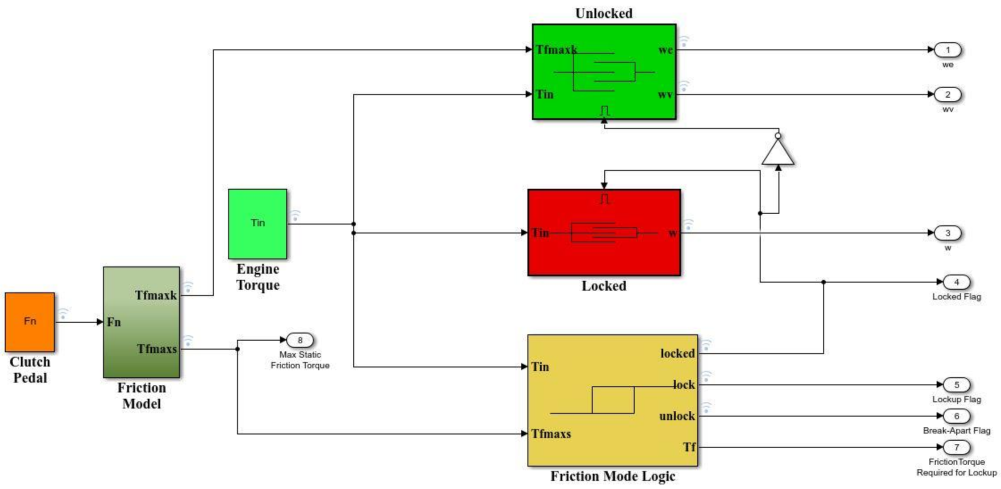

Fig. 3 The slipping and locked up clutch state model.

Simulation and Results

According to the input parameters shown in Table (1) and the Simulink model, the appropriate friction capacity in the slipping and locked-up states of the clutch has been calculated. Also, Kinetic slipping and static slipping were calculated according to the state of the clutch, whether in the slipping state or the locked-up state. The previous input parameters were used to calculate both the engine's angular speed and the vehicle's angular speed, as well as to calculate the engine torque and the clutch's normal force.

According to the results in Fig. 4 that shows the engine torque and the clutch normal force the engine torque decreases, and the clutch normal force increases until five second. Consequently, the onset of slip occurs at about t = 6.25 seconds as indicated by the separation of the engine and vehicle speeds.

Figure 5 shows that the engine angular speed and the vehicle angular speed are equal after 4.5 seconds until it returns and differs again after 6.5 seconds. Figure 6 shows the friction torque required for locked up and max friction torque, where the friction torque required for locked up equals 1.0.

Table 1 The parameters of the inputs simulation model.

Parameter	*Value*	*Parameter*	*Value*
I_e	0.8 kg.m^2	I_v	4.6 kg.m^2
b_e	1.8 Nm/rad/sec	b_v	0.9 Nm/rad/sec
μ_s	1.3	μ_k	0.8
R	1.2m		

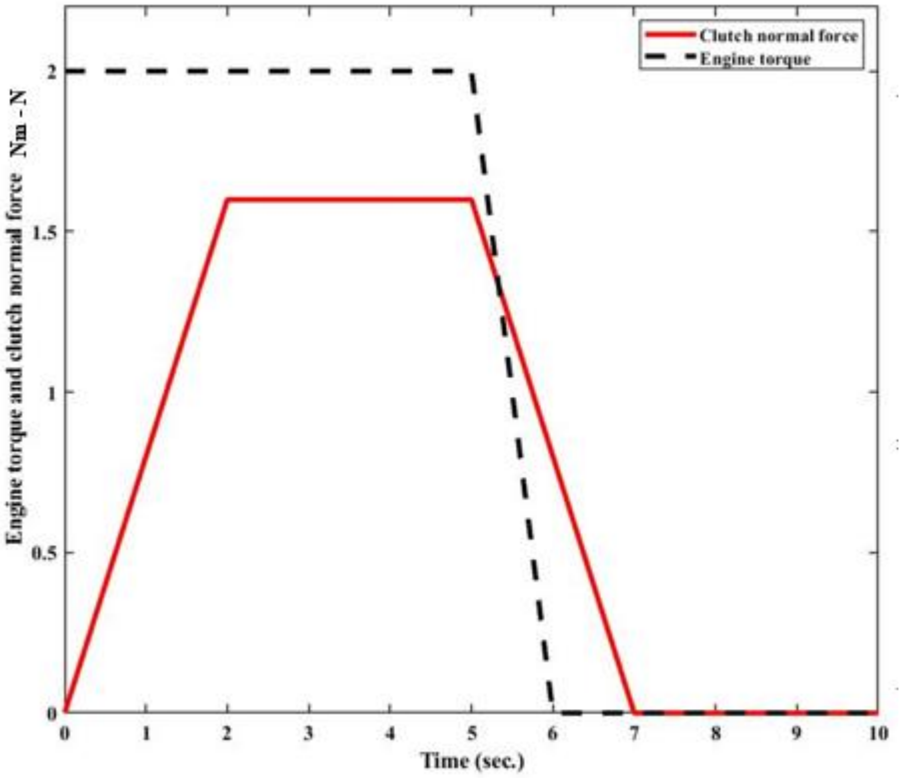

Fig. 4 The engine torque clutch normal force.

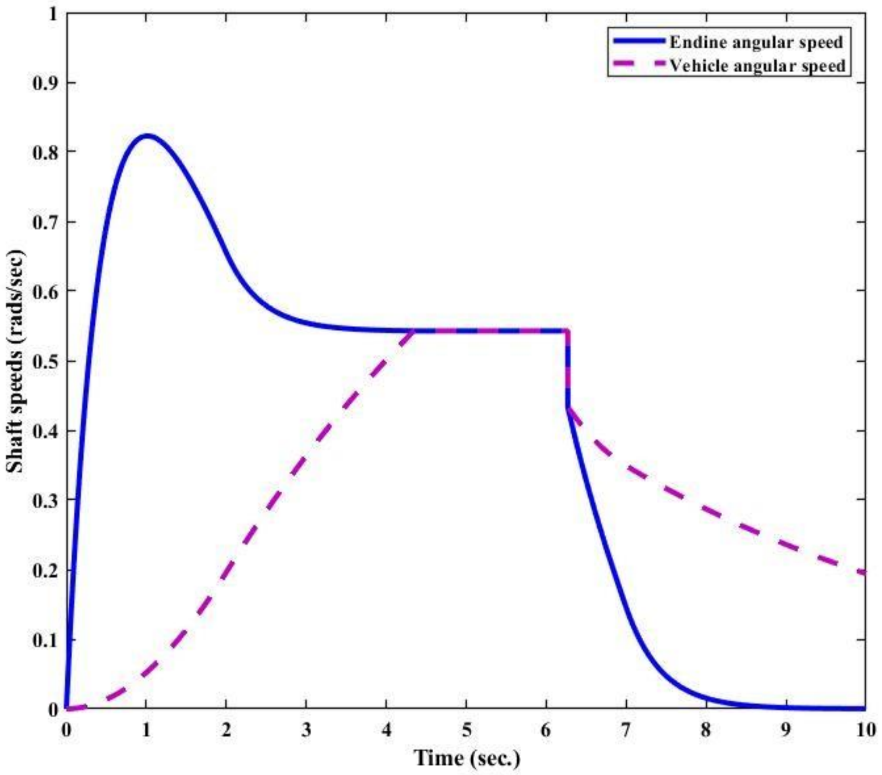

Fig. 5 The engine angular speed and vehicle.

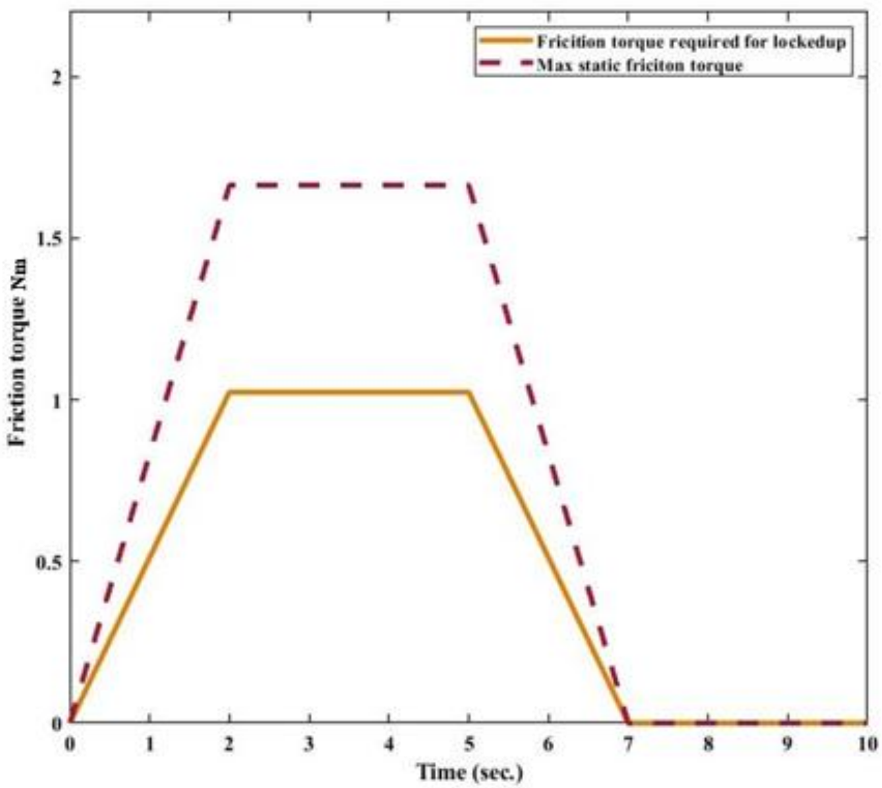

Fig. 6 The friction torque.

CONCLUSIONS

Clutches play a crucial role in ensuring effective power transmission and speed change in vehicles. Understanding how they work and the factors affecting their performance helps maintain the safety and performance of the vehicle. Different types of clutches are used to transfer powertrains in vehicles, and the different types vary according to the nature of the work. In this research, some previous studies were presented that dealt with the materials from which clutches are made. MATLAB was also used to build and create a mathematical model that simulates the operation of the clutch to study the performance of the clutch when parameters affect the performance of the clutch. The results show that the engine angular speed and the vehicle angular speed are equal after 4.5 seconds and the required friction for locking up is equal to 1.0.

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