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COMPARATIVE ANALYSIS OF PASSENGER CAR CLUTCH CONSTRUCTIONS AND THEIR OPERATIONAL CHARACTERISTICS

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Abstract

The clutch is one of the most important functional units in the transmission system of passenger cars equipped with manual or automated manual drivetrains. Its main task is to connect and disconnect the engine from the gearbox, provide smooth vehicle starting, enable gear shifting without excessive shock loads, and protect driveline components from torsional vibrations and overloads. Although the general operating principle of friction clutches has remained relatively stable for many decades, their structural design has continuously evolved due to increasing requirements for comfort, durability, compactness, thermal resistance, noise reduction, and stable torque transmission. This article presents a comparative analysis of the main clutch constructions used in passenger cars, including conventional single-plate dry clutches, diaphragm spring clutches, mechanically and hydraulically actuated clutch systems, self-adjusting clutches, torsion-damped driven discs, and compact multi-disc solutions. Special attention is paid to their operational characteristics, such as torque capacity, pedal effort, engagement smoothness, thermal loading, wear resistance, service life, and failure modes. The study also includes two simulated graphical analyses.

Keywords: passenger car, clutch, friction clutch, diaphragm spring, torque capacity, clutch disc, self-adjusting clutch, clutch wear, thermal load, transmission system.

1. Introduction

In passenger cars, the clutch is located between the engine and the gearbox and performs the essential function of temporarily interrupting and restoring the torque flow from the engine crankshaft to the transmission input shaft. During vehicle starting, the clutch allows a controlled slip between the flywheel and the driven disc, so that the vehicle can accelerate from rest without engine stall or severe driveline shock. During gear shifting, it disconnects the rotating engine from the gearbox, enabling the driver or automated actuator to change gear ratios smoothly. In addition, the clutch acts as a protective and comfort-related element because it can filter torsional fluctuations generated by the internal combustion engine and reduce impact loads in the driveline. Modern clutch systems therefore must satisfy not only mechanical strength requirements, but also comfort, thermal, tribological, and reliability requirements.

The importance of clutch construction becomes especially clear when passenger cars are operated in urban traffic conditions. Frequent stop-and-go driving, hill starts, traffic congestion, inexperienced driving style, overloaded vehicle operation, and poor maintenance can significantly increase the number of clutch engagements and the amount of generated frictional heat. ZF Aftermarket notes that clutch slipping may appear under different operating conditions and may be caused not only by the clutch disc or pressure plate, but also by the release system, incorrect installation, flywheel condition, oil contamination, and deformation of friction surfaces.

The aim of this article is to compare the main constructions of passenger car clutches and evaluate their operational characteristics. The objectives are to describe the structural elements of passenger car clutches, compare conventional and improved designs, analyze torque transmission and thermal behavior, identify typical failure modes, and present simulated graphical data that can be used in a diploma project or scientific discussion.

Literature Review

Scientific and technical literature on automotive clutches can be divided into several main directions. The first direction studies clutch torque transmission and control. The second direction analyzes thermal processes and contact pressure distribution. The third direction investigates wear, friction materials, and durability. The fourth direction focuses on torsional vibration, driveline noise, and damper design. The fifth direction deals with modern clutch actuation systems and self-adjusting mechanisms.

Serrarens and co-authors presented a dry clutch model for automotive control applications and expressed clutch torque during slip as a function of normal force, friction coefficient, and active radius. Their model shows that transmitted torque depends directly on the normal actuation force, friction coefficient, and effective radius of the clutch plates. This relationship is fundamental for clutch design because it explains why engineers can increase torque capacity by increasing clamp load, improving friction material, increasing effective radius, or increasing the number of active friction surfaces.

Thermal behavior is another key subject in clutch research. Abdullah and Schlattmann investigated temperature distribution in automotive dry friction clutches during repeated engagements. Their study considered the flywheel, clutch disc, and pressure plate, and applied finite element methods under different pressure distribution assumptions. The authors emphasized that frictional heat generated during engagement affects clutch performance and can lead to premature failure if not properly controlled. This confirms that the analysis of clutch construction must include heat generation and heat dissipation, not only static torque capacity.

Three-dimensional finite element analysis has also been used to study contact pressure in dry friction clutch systems. Sabri and co-authors developed a finite element model of a single-disc dry clutch to estimate contact pressure distribution between the flywheel, friction clutch, and pressure plate under different working conditions. The study found that contact pressure distribution is influenced by the stiffness of friction materials and that reducing structural stiffness may homogenize contact pressure and help avoid undesirable phenomena such as hot spots. This is important because uneven contact pressure can cause local overheating, vibration, uneven wear, and reduced service life.

A further important topic is the relationship between clutch engagement, oscillation, and thermal loading. Gkinis and co-authors noted that severe operating conditions such as clutch slip and increased contact pressure during engagement generate contact heat and increase clutch system temperature. They also indicated that oscillatory effects such as take-up judder can increase heat generation because of stick-slip motion. Therefore, smooth engagement is not only a comfort requirement but also a durability requirement.

The construction of the clutch driven disc is closely connected with vibration reduction. LuK technical training material explains that clutch disc torsion dampers are used to reduce rotational irregularities caused by internal combustion engines, which can otherwise create gearbox resonance and undesirable noise emissions. The same material also describes lining resilience systems that support smooth torque build-up and improve contact behavior throughout the disc life. These features show that the clutch disc is not merely a friction plate, but a complex dynamic component.

Xie and co-authors studied a clutch-driven disc assembly with a wide-angle, large-hysteresis, multistage damper. They noted that torsional vibration in the vehicle driveline increases loads on shafts, bearings, gears, and housings, and can also increase interior noise. They also explained that torsional dampers are commonly arranged on clutch-driven disc assemblies to reduce driveline vibration and noise. This supports the conclusion that damper design is one of the most important indicators of clutch operational quality.

Self-adjusting clutch technology is another modern improvement. Schaeffler's self-adjusting clutch principle uses a sensor diaphragm spring and adjustment mechanism to compensate for friction lining wear. According to the technical description, when facing wear increases release load, the sensor spring allows the pivot point of the main diaphragm spring to move and return the release load toward its original level. The design can reduce release load variation and increase wear capacity. This is highly relevant for passenger cars because stable pedal force and long service life are important for comfort and reliability.

Based on the reviewed literature, it can be concluded that the operational quality of a passenger car clutch depends on several interrelated parameters: normal clamp force, friction coefficient, effective radius, thermal capacity, pressure distribution, damping characteristics, wear compensation, and actuation accuracy. Therefore, a comparative analysis must be multidimensional.

Methodology

The methodology of this article is based on analytical comparison, technical classification, and simplified numerical simulation. First, the main clutch constructions used in passenger cars are classified according to friction type, spring type, actuation system, driven disc construction, and wear compensation mechanism. Second, each construction is evaluated according to operational criteria: torque capacity, engagement smoothness, pedal effort, thermal resistance, durability, maintenance complexity, cost, and suitability for passenger car use. Third, two simplified simulations are prepared to support the discussion visually.

The first simulation evaluates clutch torque capacity using the commonly applied friction torque relationship:

$$\mathbf{T = \mu \cdot Fn \cdot Rm \cdot z}$$

where **T** is the torque capacity, **μ** is the coefficient of friction, **Fn** is the normal clamp force, **Rm** is the effective mean friction radius, and **z** is the number of active friction surfaces. This simplified equation is consistent with the physical relationship used in dry clutch modeling, where transmitted torque depends on normal force, friction coefficient, and active radius.

For the simulation, three representative clutch layouts are considered. The first is a conventional diaphragm single-disc clutch. The second is a self-adjusting diaphragm single-disc clutch with slightly higher effective clamp force stability. The third is a compact twin-disc performance clutch, which has more active friction surfaces but is more complex and expensive. The simulation is illustrative and does not represent a specific vehicle model. Its purpose is to show how constructional parameters influence torque capacity.

Diaphragm Spring Clutch

The diaphragm spring clutch is the standard construction for many modern passenger cars. Instead of multiple coil springs, it uses one conical diaphragm spring. The diaphragm spring performs two functions: it generates clamp load and acts as a release lever through its radial fingers. This integrated function reduces the number of components and allows a compact design.

The main advantage of the diaphragm spring is its favorable force-displacement characteristic. In comparison with coil spring designs, it can provide a more stable clamp load and lower release effort within the useful operating range. This improves driver comfort, especially in urban traffic where the clutch pedal is operated frequently. The diaphragm spring also distributes load more evenly around the pressure plate, which can improve contact behavior and reduce local pressure peaks.

The diaphragm spring clutch is also suitable for hydraulic release systems. In modern designs, a concentric slave cylinder can push directly on the diaphragm fingers through a release bearing. This arrangement reduces the number of external mechanical parts and can improve packaging. ZF notes that in diaphragm-spring clutch systems with suitable preload, the release bearing and diaphragm spring thrust ring can run at the same speed, reducing noise and wear from speed differences.

However, diaphragm spring clutches also require accurate design and installation. Excessive release travel can damage diaphragm fingers or cause contact with the torsional damper. Misalignment between the engine and transmission can cause uneven release bearing contact and wear of diaphragm spring tips. ZF's technical information states that diaphragm spring tip wear can be caused by low release bearing preload, worn actuation systems, worn guide tubes, or poor centering between engine and transmission.

In operation, the diaphragm spring clutch provides a good balance of torque capacity, comfort, compactness, and manufacturability. For this reason, it is generally the most rational solution for mass-produced passenger cars.

Torque Capacity Simulation

The first simulated graph compares the torque capacity of three representative passenger car clutch layouts as the friction coefficient changes from 0.25 to 0.45. The layouts are conventional diaphragm single-disc clutch, self-adjusting diaphragm single-disc clutch, and compact twin-disc performance clutch. The simulation is based on the equation $\mathbf{T = \mu \cdot Fn \cdot Rm \cdot z}$. It is important to emphasize that the values are not taken from a specific production car; they are selected for comparative educational analysis.

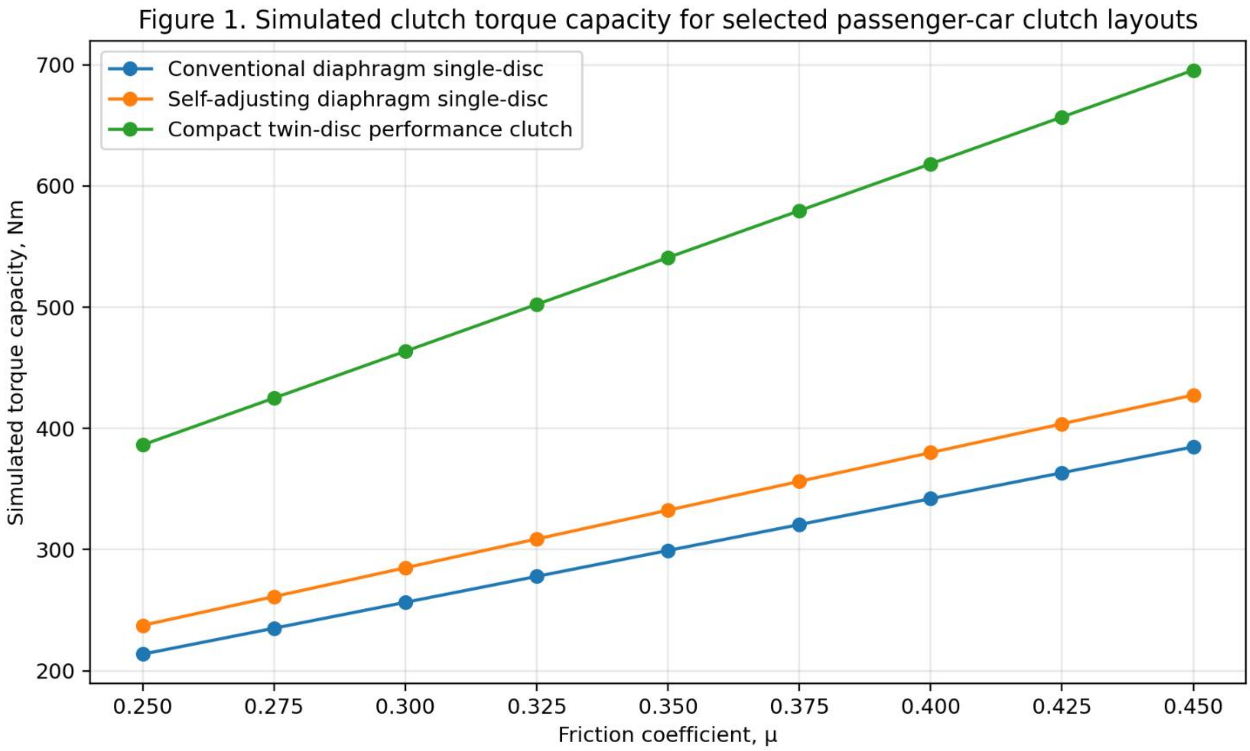

Figure 1. Simulated clutch torque capacity for selected passenger-car clutch layouts.

The graph shows that torque capacity increases almost linearly with the friction coefficient. This is expected because the friction coefficient is directly proportional to torque capacity in the

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simplified model. The self-adjusting diaphragm single-disc clutch has slightly higher simulated torque capacity than the conventional clutch because its effective clamp load is assumed to be more stable. The compact twin-disc clutch shows the highest torque capacity because it has more active friction surfaces. However, this does not automatically mean that the twin-disc clutch is the best solution for ordinary passenger cars. It is more complex, more expensive, and may provide less smooth engagement if not carefully designed.

The graph supports an important engineering conclusion: increasing the coefficient of friction alone is not always the best solution. A friction lining must also provide stable behavior at high temperature, low wear, low noise, and good engagement quality. Similarly, increasing clamp load improves torque capacity, but may increase pedal effort and bearing load. Increasing the number of friction surfaces improves torque capacity, but increases structural complexity. Therefore, clutch design must be optimized according to vehicle class, engine torque, driving conditions, and cost.

Thermal Simulation During Repeated Engagements

The second simulated graph presents the possible increase in peak interface temperature during repeated clutch engagements. Three cases are shown: conventional organic lining, grooved or composite lining, and high-load city driving case. The graph is illustrative and uses a simplified lumped thermal response. It does not replace experimental measurement or finite element modeling.

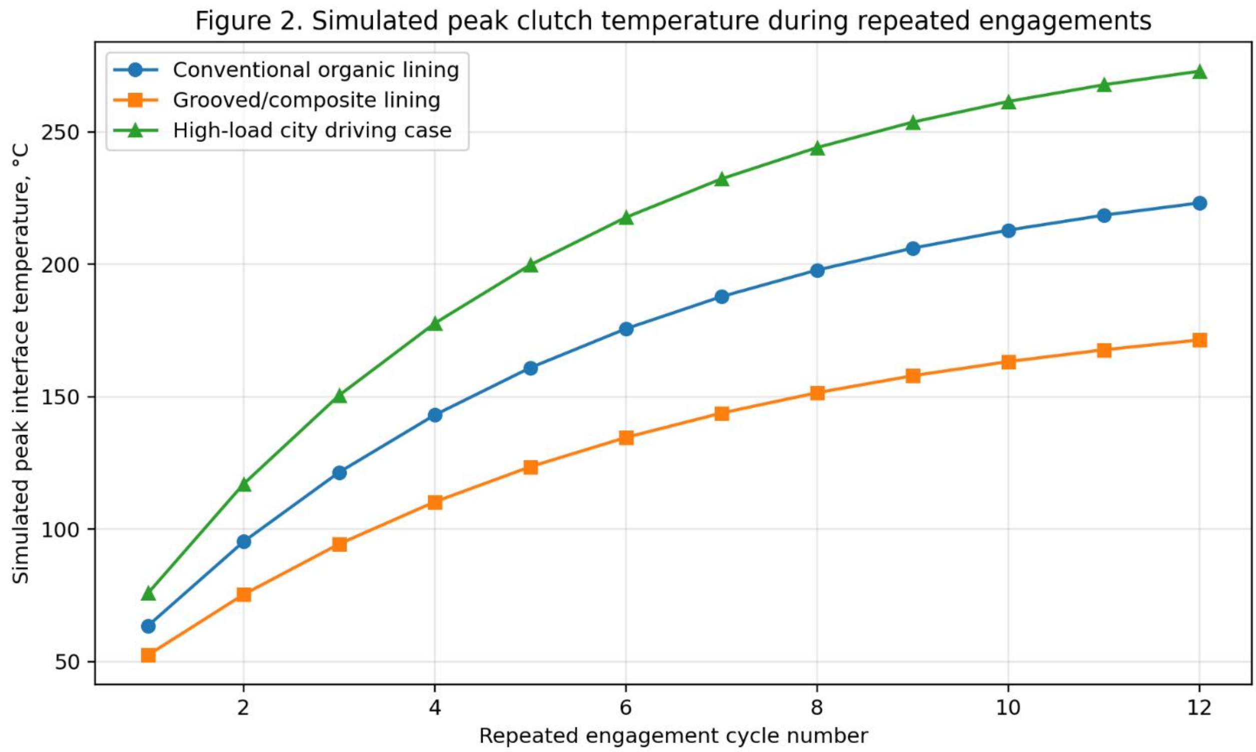

Figure 2. Simulated peak clutch temperature during repeated engagements.

The graph shows that repeated engagements can cause cumulative temperature rise. The high-load city driving case reaches the highest temperature because the assumed slip energy is greater and cooling time is insufficient. The conventional organic lining shows moderate temperature growth, while the grooved or composite lining demonstrates lower simulated peak temperature due to assumed better heat dissipation and thermal stability.

This simulation is consistent with the general findings of thermal clutch research. Finite element studies have shown that dry clutch temperature distribution depends on repeated engagements, pressure distribution, convection, and contact conditions. Other studies also indicate that clutch slip and contact pressure during engagement generate heat and can increase the temperature of clutch linings.

From an operational perspective, temperature is one of the most important factors affecting clutch durability. Excessive temperature can reduce the friction coefficient, burn the lining, damage the binder material, warp the pressure plate, create hot spots, and lead to judder or slip. ZF notes that constant clutch slip generates more heat than can be absorbed, which results in overheating. Therefore, clutch construction must provide not only sufficient torque capacity but also safe thermal behavior.

Conclusion

This article presented a comparative analysis of passenger car clutch constructions and their operational characteristics. The study showed that the clutch is a complex transmission unit whose performance depends on the interaction of friction, clamp force, spring characteristics, actuation system, damping elements, thermal behavior, and wear compensation. The conventional single-plate dry clutch remains attractive because of its simplicity and low cost, but the diaphragm spring clutch provides better comfort, compactness, and load characteristics. Hydraulic actuation and concentric slave cylinders improve control comfort and packaging, while self-adjusting clutches compensate for lining wear and maintain stable release load over service life. Torsion-damped clutch discs are essential for reducing driveline vibration and improving NVH behavior.

The first simulation demonstrated that clutch torque capacity increases with friction coefficient, clamp force, effective radius, and the number of active friction surfaces. However, the highest torque capacity is not always the best design criterion because cost, smoothness, thermal behavior, and serviceability must also be considered. The second simulation showed that repeated engagements can significantly increase clutch temperature, especially under high-load city driving conditions. This confirms that thermal resistance and heat dissipation are critical factors in clutch durability.

The most rational construction for ordinary passenger cars is a diaphragm spring single-disc dry clutch with a torsion-damped driven disc and reliable hydraulic or mechanical actuation. For higher comfort and durability, a self-adjusting mechanism is recommended. For high-performance or specialized vehicles, multi-disc or dual-clutch systems may be applied, but their increased complexity must be justified by operating requirements.

Thus, the comparative analysis confirms that passenger car clutch design must be evaluated as a system. A durable and comfortable clutch is achieved not by one parameter alone, but by the balanced optimization of torque capacity, friction material, pressure distribution, damping performance, actuation accuracy, thermal stability, and maintenance suitability.

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