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REDUCING WEAR FACTORS AND IMPROVING THE CONSTRUCTION OF PASSENGER CAR CLUTCHES DURING OPERATION

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Abstract

The clutch is one of the most important units of the passenger car transmission system because it provides controlled connection and disconnection between the engine and the gearbox. During vehicle starting, gear shifting, maneuvering in traffic, hill climbing, and low-speed operation, the clutch works under repeated frictional contact, variable torque, thermal loading, and mechanical vibration. As a result, the clutch disc lining, pressure plate, flywheel surface, release bearing, diaphragm spring, torsional damper, and actuation mechanism are exposed to wear and functional degradation. Premature clutch wear is one of the common causes of reduced vehicle reliability, poor acceleration, slipping, vibration, burning smell, difficult gear shifting, and increased maintenance cost. Therefore, the reduction of clutch wear and the improvement of clutch construction are important engineering tasks in the field of passenger car design and technical operation.

Keywords: passenger car, clutch, friction lining, wear reduction, diaphragm spring, clutch disc, self-adjusting clutch, thermal load, torque transmission, construction improvement.

1. Introduction

The transmission system of a passenger car is designed to transfer engine torque to the driving wheels in a controlled and efficient way. In vehicles equipped with a manual transmission or an automated manual transmission, the clutch performs the key function of connecting and disconnecting the engine from the gearbox. When the driver starts the vehicle from rest, the clutch allows controlled slip between the flywheel and the driven disc. This slip makes it possible to gradually increase transmitted torque and prevent engine stalling. During gear shifting, the clutch interrupts torque flow and allows the gearbox synchronizers to operate under more favorable conditions. Therefore, the clutch is not only a torque transmission element, but also a comfort, safety, and durability component of the vehicle.

During operation, the clutch is exposed to severe working conditions. Each engagement produces friction between the clutch lining, flywheel, and pressure plate. The generated frictional energy is converted into heat. If the slip duration is short and the load is moderate, this heat can be absorbed and dissipated by the flywheel, pressure plate, clutch cover, and surrounding air. However, in urban driving conditions, repeated starting, traffic congestion, hill starts, and partial clutch engagement can create excessive thermal loading. Research on automotive dry clutch engagement shows that high interfacial slip and contact pressure generate heat, which affects friction material behavior, lining wear, disc distortion, and useful clutch life.

The operational life of a clutch depends on several interrelated factors. These include friction lining material, clamp load, effective friction radius, contact pressure distribution, temperature, slip speed, engagement time, flywheel condition, release bearing operation, diaphragm spring characteristics, and driver behavior. If one of these factors becomes unfavorable, clutch wear accelerates. For example, if the driver frequently keeps the foot on the clutch pedal, the release system may partially unload the pressure plate and cause slipping. If the clutch is overheated, the friction coefficient may become unstable and the lining may burn. If the flywheel or pressure plate surface becomes warped, contact pressure becomes non-uniform and local hot spots may appear. If oil or grease contaminates the friction lining, the clutch may slip even when the lining thickness is still sufficient.

The problem of clutch wear is especially relevant for passenger cars used in cities. In city traffic, the clutch is engaged and disengaged many times per trip. Inexperienced drivers may hold the vehicle on a slope using clutch slip instead of the brake. Taxi vehicles, training cars, delivery cars, and vehicles used in mountainous regions often experience a much higher number of clutch engagements than vehicles used mainly on highways. As a result, the same clutch construction may have different service lives depending on operating conditions.

The purpose of this article is to analyze the main wear factors of passenger car clutches and to propose technical solutions for reducing wear and improving clutch construction. The research is based on theoretical analysis, review of engineering literature, and simplified simulation graphs. The article is focused mainly on dry single-disc diaphragm spring clutches because this construction is one of the most common in passenger cars. However, the proposed principles can also be useful for understanding other clutch types.

2. Literature Review

The scientific literature on clutch wear and constructional improvement can be divided into several directions. The first direction investigates heat generation and temperature distribution during clutch engagement. The second direction studies friction material behavior and wear mechanisms. The third direction examines pressure distribution, contact deformation, and finite element modeling. The fourth direction studies self-adjusting clutch mechanisms and actuation force stability. The fifth direction analyzes dynamic engagement, torsional vibration, and drivability.

Thermal behavior is one of the most important topics in clutch research. Abdullah and Schlattmann performed transient thermal analysis of an automotive dry friction clutch during repeated engagements. Their model considered the flywheel, clutch disc, and pressure plate during both the heating phase and the cooling phase. They used two thermal load assumptions: uniform pressure and uniform wear. Their study showed that after ten repeated engagements, the maximum temperature exceeded 527 K in both loading cases, and they concluded that repeated engagements can rapidly increase clutch temperature and may lead to premature failure before the expected lifetime.

Gkinis and co-authors investigated heat generation and transfer in automotive dry clutch engagement. They emphasized that dynamic behavior of a dry clutch depends on the frictional characteristics between the lining material, flywheel, and pressure plate. Their research showed that heat generation during clutch engagement affects material behavior, friction characteristics, lining wear, thermal distortion, and useful service life. They also found that worn lining may remove heat less efficiently due to changes in thickness, density, and thermal conductivity.

Modern clutch research also pays attention to modeling torque transmission and wear-related factors. A recent modeling study on dry friction clutches states that torque transmission is influenced by temperature, sliding speed, contact pressure, and wear. The same study notes that thermal characteristics can be improved by selecting appropriate friction material and using better-designed groove patterns. This means that clutch durability cannot be improved only by increasing clamp force; it requires a combination of material, geometry, and thermal design solutions.

Another important area is diaphragm spring and engagement characteristics. Yan and co-authors note that diaphragm spring clutches are widely used in manual transmissions and automated manual transmissions, and that their engagement and disengagement characteristics determine smooth starting and shifting performance. They also state that unmatched engagement and disengagement characteristics can cause driver fatigue, improper shifting, friction plate damage, transmission failure, and reduced service life. This confirms the importance of precise constructional design of the diaphragm spring, cushion plate, friction plate, and release mechanism.

3. Materials and Methods

The research method used in this article is analytical and simulation-based. The article does not claim to present experimental test bench data from a specific production vehicle. Instead, it uses general engineering principles and simplified simulation curves to explain how clutch wear develops and how constructional improvements may reduce it. Such an approach is suitable for a diploma project because it connects theoretical design analysis with practical operating conditions.

The object of analysis is a typical passenger car dry single-disc diaphragm spring clutch. The main components considered are the flywheel, clutch disc, friction lining, pressure plate, diaphragm spring, clutch cover, release bearing, release fork or hydraulic slave cylinder, and torsional damper. The study considers both conventional and improved clutch constructions.

The main wear factors included in the analysis are friction lining wear, thermal degradation, pressure plate and flywheel surface damage, loss of clamp load stability, release bearing wear, diaphragm spring finger wear, torsional damper spring wear, and contamination. In practical operation, these factors do not appear separately. For example, overheating may reduce the friction coefficient, increase slipping, create more heat, and accelerate lining wear. Similarly, a release system defect may cause incomplete engagement, which creates slip and heat.

For the first simulation, cumulative lining wear was modeled as a function of engagement cycles. Three cases were compared: conventional organic lining, improved composite lining, and improved lining combined with optimized clamp load. The assumed wear trend is nonlinear because wear usually accelerates when temperature, surface damage, and pressure instability increase. The simulation is not intended to represent one exact vehicle model; it is a comparative illustration.

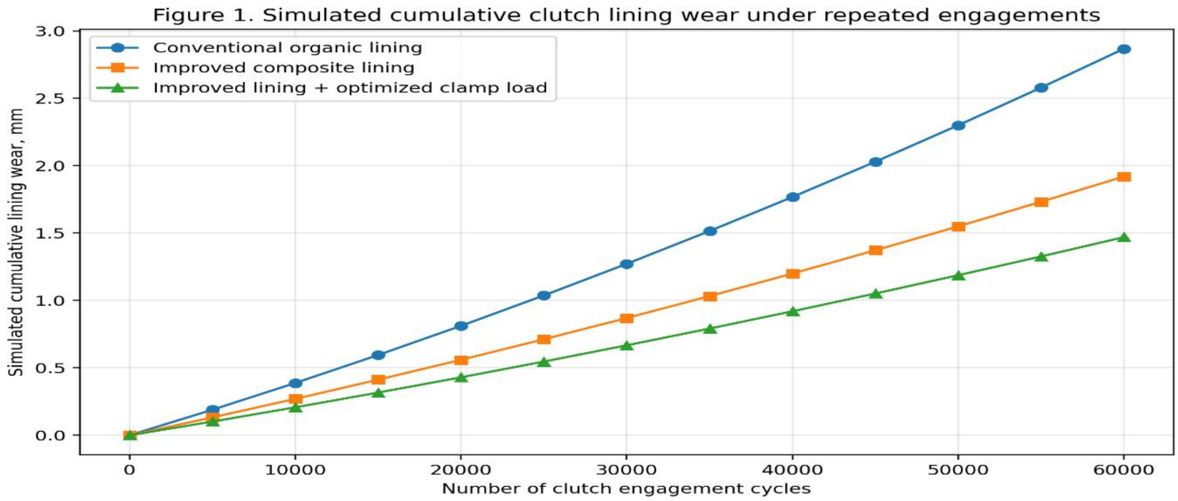

Figure 1. Simulated cumulative clutch lining wear under repeated engagements.

For the second simulation, peak interface temperature was modeled during repeated clutch engagements. Three constructional cases were compared: conventional disc, grooved friction surface, and grooved surface with higher-conductivity lining. The model assumes that repeated engagements without sufficient cooling produce cumulative heating. This is consistent with the results of thermal clutch studies, where repeated engagements significantly increase the temperature of the clutch contact surfaces.

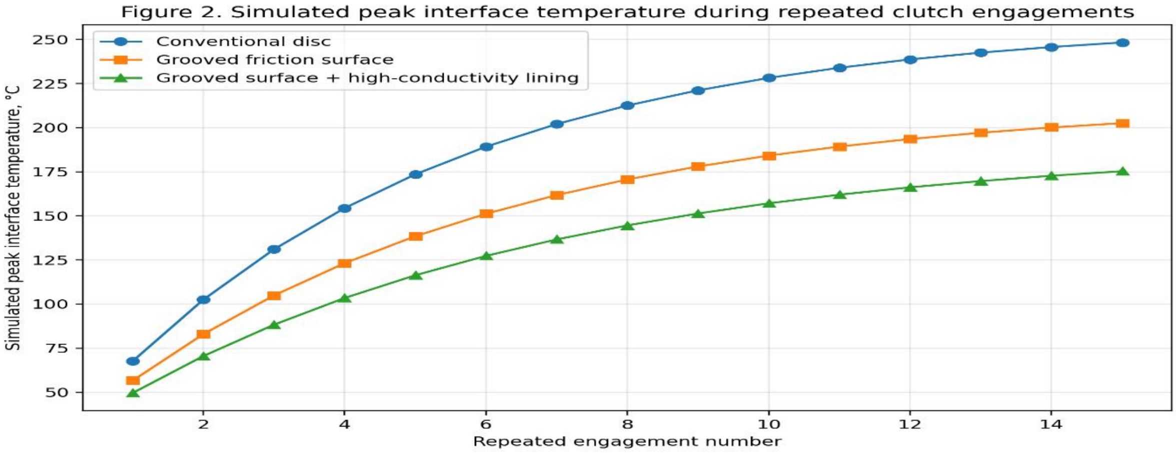

Figure 2. Simulated peak interface temperature during repeated clutch engagements.

For the third simulation, the probability of serviceable clutch condition was modeled as a function of mileage. Three cases were compared: conventional clutch, self-adjusting clutch, and an integrated improvement package. The integrated package includes improved friction lining, optimized pressure distribution, self-adjusting wear compensation, better thermal behavior, and improved actuation accuracy. This graph is also illustrative and is used to demonstrate the expected direction of improvement.

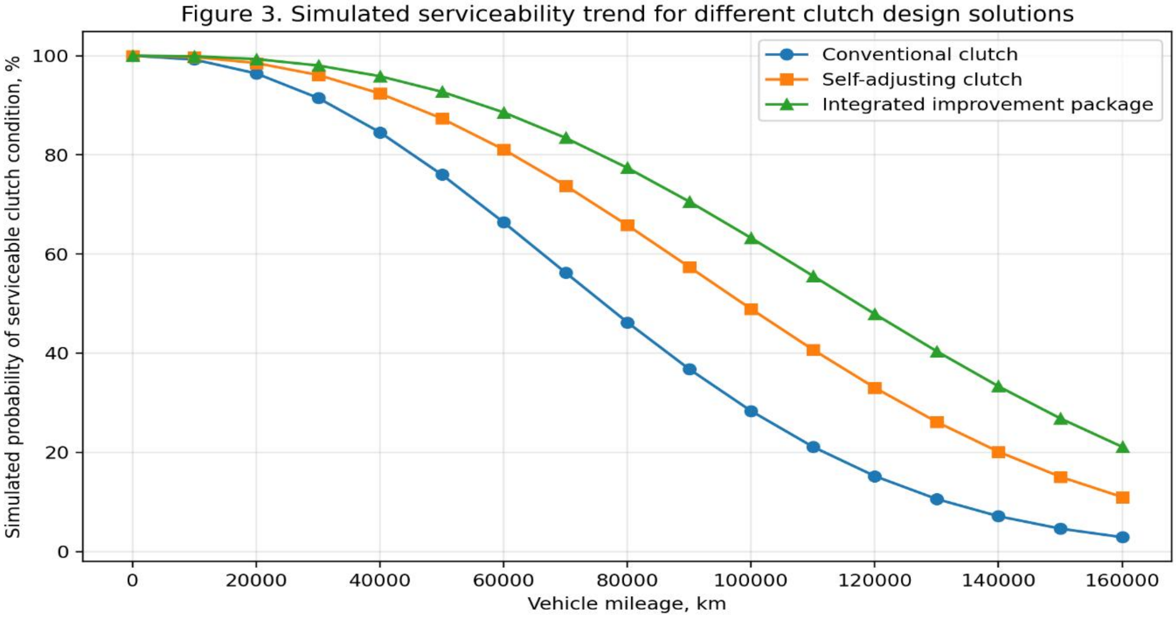

Figure 3. Simulated serviceability trend for different clutch design solutions.

Open Figure 3

The evaluation criteria used in this study include wear resistance, thermal stability, torque transmission stability, pedal effort stability, engagement smoothness, maintenance complexity, and expected service life. These criteria were selected because they directly influence the operational quality of passenger car clutches.

4. Results

The first result of the analysis is that friction lining wear is strongly affected by the number of engagements, slip duration, contact pressure, friction coefficient stability, and temperature. In Figure 1, the conventional organic lining shows the highest simulated wear growth. This is because conventional linings may have lower thermal stability under repeated high-energy engagements. The improved composite lining shows lower wear growth because better material stability can reduce surface degradation. The best result is obtained when improved lining is combined with optimized clamp load. This shows that material improvement alone is useful, but the best effect appears when material and structural parameters are optimized together.

The second result is that temperature rise is a critical cause of accelerated wear. Figure 2 shows that the conventional disc reaches the highest simulated temperature after repeated engagements. The grooved friction surface reduces the peak temperature because grooves can support heat transfer, remove wear particles, and improve contact behavior. The grooved surface combined with higher-conductivity lining gives the lowest simulated temperature. This result agrees with the engineering idea that groove patterns and friction material selection can improve clutch thermal behavior. Modeling literature also notes that the thermal characteristics of dry friction clutches can be enhanced by selecting suitable materials and using better groove patterns.

The third result is that wear compensation improves long-term operational stability. Figure 3 shows that the conventional clutch has the fastest decrease in simulated serviceability. The self-adjusting clutch maintains a higher serviceability level because it compensates for lining wear and keeps actuation force more stable. The integrated improvement package gives the best result because it combines wear compensation with improved material and thermal design. This is consistent with technical descriptions of the self-adjusting clutch, which state that wear adjustment helps maintain actuation force and clamp load stability throughout clutch life.

5. Discussion

The reduction of clutch wear must be understood as a complete system design problem. In practice, many clutch failures occur not because one component is weak, but because several unfavorable factors act together. For example, a slightly worn lining, a weak diaphragm spring, a rough flywheel surface, and a driver who frequently slips the clutch can together create rapid failure. Therefore, constructional improvement must address the friction pair, the pressure mechanism, the release mechanism, and the damping system.

The first direction of improvement is the use of more stable friction materials. The friction lining must provide a stable coefficient of friction over a wide range of temperatures and pressures. It must resist wear, avoid excessive dust formation, maintain mechanical strength, and provide smooth engagement. Organic linings are suitable for ordinary passenger cars because they provide smooth operation and acceptable cost. However, for vehicles operating under heavier conditions, composite linings with improved thermal stability may be more effective. The material should not be selected only by a high friction coefficient because a very aggressive lining may increase flywheel and pressure plate wear. The correct solution is a balanced material with stable friction, sufficient thermal resistance, and acceptable wear behavior.

The second direction is the optimization of contact pressure distribution. Uneven pressure distribution creates local hot spots, uneven wear, and vibration. The geometry of the pressure plate, stiffness of the clutch cover, diaphragm spring characteristic, flywheel flatness, and cushion plate design all influence pressure distribution. If the pressure is too concentrated near one radius, the lining will wear unevenly. If the pressure plate deforms under thermal load, contact becomes unstable. Therefore, finite element analysis can be useful during design to predict deformation and pressure distribution. Research on dry clutch contact and engagement modeling confirms that friction coefficient, cushion plate behavior, pressure plate temperature, and torsional damper characteristics influence clutch torque and engagement behavior.

The third direction is thermal management. Heat is the main enemy of clutch durability. During slip, mechanical energy is converted into heat at the friction interface. If heat is not removed effectively, the lining temperature increases, the friction coefficient becomes unstable, and the pressure plate may warp. The flywheel and pressure plate should have sufficient thermal mass and conductivity. Ventilation around the clutch housing should not be ignored. Grooves on the friction lining can help remove wear particles and support more stable thermal behavior. However, groove design must be optimized because excessive grooving can reduce contact area and torque capacity.

The fourth direction is the use of self-adjusting mechanisms. In conventional clutches, facing wear changes the diaphragm spring position and increases actuation force. In the self-adjusting clutch, the wear adjustment system compensates for lining thickness reduction. This makes pedal effort more stable and can increase service life. According to LuK technical material, the self-adjusting clutch can reduce required actuation forces and increase clutch life by around 1.5 times. For passenger cars with higher engine torque or frequent urban operation, this solution is technically justified. However, self-adjusting clutches are more complex and require correct installation procedures. If installed incorrectly, the adjustment mechanism may not work properly.

The fifth direction is improvement of the release system. The clutch must fully engage and fully disengage. If the release bearing, fork, cable, master cylinder, slave cylinder, or hydraulic line does not operate correctly, the clutch may remain partially released or may not disengage completely. Partial release during driving causes slip and rapid wear. Incomplete disengagement causes difficult gear shifting and synchronizer wear. Hydraulic actuation can improve comfort and control accuracy, but it must be free from air and leaks. A concentric slave cylinder can improve packaging and reduce external mechanical parts, but repair may be more difficult because it is located inside the bell housing.

The sixth direction is torsional damper improvement. The clutch disc damper reduces engine torque pulsations and protects the gearbox from vibration. If the damper springs are too stiff, the vehicle may experience harsh engagement and gear rattle. If they are too soft, the driveline response may become unstable. A multistage torsional damper can provide softer behavior at low torque and stronger support at higher torque. This improves comfort and reduces dynamic loads on the friction surfaces. Better damping also helps reduce stick-slip behavior and engagement shock.

The seventh direction is driver behavior and maintenance control. Even the most advanced clutch can fail prematurely if used incorrectly. Riding the clutch pedal, holding the car on slopes with clutch slip, aggressive starts, towing excessive loads, and starting in the wrong gear can all increase wear. Maintenance is also important. Oil leaks from the engine rear main seal or transmission input shaft seal can contaminate the clutch lining. A worn flywheel surface should be machined or replaced according to technical requirements. The release bearing should be replaced when the clutch assembly is replaced. The hydraulic system should be bled correctly.

6. Proposed Constructional Improvement Concept

Based on the analysis, an improved passenger car clutch construction can be proposed. The improved construction should use a diaphragm spring single-disc clutch as the base because this layout is compact, cost-effective, and suitable for passenger cars. The first improvement is the use of a composite organic lining with higher thermal stability and lower wear rate. The lining should have optimized grooves for heat dissipation and wear particle removal. The groove pattern should not excessively reduce the effective contact area.

The second improvement is an optimized pressure plate and cover stiffness. The pressure plate should resist thermal deformation, and the cover should maintain stable clamp load under repeated operation. The diaphragm spring should be selected to provide sufficient torque reserve with acceptable pedal effort. The third improvement is the use of a self-adjusting wear compensation mechanism. This mechanism should maintain the diaphragm spring in a favorable position as lining wear increases, keeping actuation force and clamp load stable.

The fourth improvement is the use of a hydraulic release system with precise control and low friction. For compact vehicles, a concentric slave cylinder can be used. The release bearing should have sufficient durability and proper preload. The fifth improvement is a multistage torsional damper in the clutch disc. This damper should reduce engine torsional vibration and improve engagement smoothness. The sixth improvement is improved sealing and contamination protection. The clutch housing should be protected from oil leaks and external dust as much as possible.

The proposed construction does not radically change the basic clutch principle. Instead, it improves weak points that commonly cause wear: unstable friction, overheating, non-uniform pressure, release force variation, vibration, and contamination. This makes the concept realistic for passenger car applications.

7. Practical Significance

The practical significance of this study is that it can be used in the design, maintenance, and educational analysis of passenger car clutches. For designers, the article shows that clutch improvement must be based on system-level optimization. For service specialists, it explains why replacing only the clutch disc may not solve the problem if the flywheel, pressure plate, release bearing, or hydraulic system is defective. For students, the article provides a clear connection between construction, operating conditions, and failure modes.

The three simulation graphs can be used in a diploma project as visual support. Figure 1 explains how improved lining and optimized clamp load can reduce cumulative wear. Figure 2 shows why repeated engagements and thermal loading are dangerous for clutch durability. Figure 3 demonstrates how self-adjusting and integrated designs can increase the probability of serviceable clutch condition over vehicle mileage. These graphs should be presented as comparative simulations, not as exact experimental results from a particular vehicle.

8. Conclusion

The clutch of a passenger car operates under complex mechanical, thermal, and tribological conditions. Its wear is caused by repeated frictional contact, slip, heat generation, pressure non-uniformity, vibration, contamination, and changes in release mechanism geometry. The most important wear factors are friction lining degradation, overheating, unstable friction coefficient, diaphragm spring load variation, release system defects, flywheel and pressure plate deformation, and improper driving behavior.

The analysis showed that reducing clutch wear requires a combination of constructional and operational measures. Improved friction materials can reduce lining wear and provide more stable friction behavior. Optimized groove patterns and better thermal conductivity can reduce peak interface temperature. Uniform contact pressure can prevent local hot spots and uneven wear. Self-adjusting clutch mechanisms can compensate for facing wear and keep actuation force nearly constant. Improved hydraulic actuation can increase control accuracy and reduce incomplete engagement or disengagement. Multistage torsional dampers can reduce vibration and improve engagement smoothness.

The simulation results support these conclusions. The cumulative wear graph showed that improved material and optimized clamp load can significantly reduce simulated lining wear. The temperature graph showed that grooved and thermally improved designs can reduce peak interface temperature during repeated engagements. The serviceability graph showed that self-adjusting and integrated improvement concepts can maintain better clutch condition over longer mileage.

Therefore, the most effective way to improve passenger car clutch construction is not to increase one parameter alone, but to optimize the whole system. A reliable clutch should combine stable friction material, sufficient clamp load, uniform pressure distribution, effective thermal management, wear compensation, precise actuation, and good torsional damping. Such an approach can increase service life, reduce maintenance cost, improve driving comfort, and enhance the reliability of passenger car transmission systems.

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