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Research Article

Single friction plate clutch design for cars with power of 77 kW and speed of 6000 rpm using finite element method

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ABSTRACT

A single friction plate clutch is one part of the components in a vehicle that is used to transmit power and rotation from the driveshaft to the driven shaft without slippage. This study aims to compare the results of mathematical calculations with analysis based on finite element methods in the design of a single friction plate clutch such as shaft, spline, friction plate, and spring. The analysis was carried out on the shaft made of S30C, spline made of S30C, friction plates made of steel alloy, and springs made of carbon steel. The component was drawn by Solidworks-17 software and analysed by Abaqus 6.14-5 software based on finite element methods. The study was performed by comparing the sizes of the various elements. A comparison of simulation processes using the stress concept of von-misses was conducted. The results of mathematical calculations with the simulation process were compared, and the maximum deviation was 2.881%. The deviation was considered acceptable. Based on von-misses' maximum stress, the material was safe to use due to below the yield strength.

1. INTRODUCTION

A clutch is a mechanism that transmits power from the motor to other driven components employing friction. The main components of a friction clutch are a flywheel, a friction plate, a diaphragm spring, and a pressure plate. The friction plate is commonly located between the flywheel and the pressure plate [1-4].

In the single plate friction clutch, the friction plate is mounted on a hub that can move freely and axially moves in the direction of the spline shaft. The transmission process occurs when the pressure plate pushes the friction plate using a diaphragm spring to the flywheel mounted on the drive shaft. On the other hand, the power transmission stops when the pressure plate releases the friction plate from the flywheel.

Friction materials are classified as semi-metals, organic materials, and ceramics [5]. The primary purpose of friction material is to get a good coefficient of friction with a low wear rate [6]. Semi-metallic materials consist of a mixture of metals such as iron, steel, or copper and organic materials. Semi-metallic materials are used in heavy load vehicles because of their high durability and relatively low coefficient of friction. The organic material is made initially of asbestos, but due to health problems, it has been replaced by a mixture of fibreglass and brass [7-9]. Organic material is used in vehicles with average power and speed. Ceramic materials are far more expensive to produce and are usually used for racing cars [10].

Surface grooves in the friction layer are used to prevent slippage during release and also reduce the temperature and internal energy of friction clutch [11]. When the clutch is rubbing against each other, slippage occurs when the shaft is driven equal to the speed of the driving shaft. This slip causes heat energy to be generated when the clutch material rubs against the flywheel [12]. With higher relative speed and continuous use, a higher friction temperature is produced on the surface of the clutch plate. The heat generated is absorbed by pressure plates and friction plates. The kinetic friction coefficient is gradually reduced so that the temperature of the rubbing material decreases. It can cause increased slippage. The friction material has to maintain high friction throughout the lifetime of the transmission and be able to withstand the high temperatures and pressures [13-15].

Clutch damage usually occurs when exposed to high temperatures resulting from the formation of friction heat. It can cause deformation and cracking, which can lead to increased slippage time and ultimately damage to components. The surface roughness of the flywheel and the friction layer is also a significant factor in wear and can cause more rapid damage.

The selection of material with suitable mechanical, physical, and technological properties is very influential in the design process. However, there is always the possibility of a failure in the design results. For this reason, it is necessary to consider effective methods that could be used in the redesign process. The methods should save time and cost in the design process [16].

Some researchers have performed clutch design and modelling using software-based finite element methods. Several commercial software such as Catia, Solid-works, Abaqus, Ansys, and Pro/Engineer is used for the design process. In addition to commercial software, open-source software is also available such as Impact, GID, and LISA.

Deshbhratar [17] designed structural single plate friction couplings. In the design process, knowledge of thermo-elasticity friction clutches was essential. The components analysed were clutch plates, diaphragm springs, and friction material. Materials used from the three components are structural steel, grey cast iron, and 49 Aramid fibre Kevlar. The stresses and forces on the clutch discs were analysed using Pro/ENGINEER and ANSYS software. Based on the results of the analysis noted that the voltage value was smaller than the allowable voltage for specific conditions. Therefore, the design was safe, and an efficient clutch design could be obtained.

Purohit [18] presented the design and finite element analysis of the automotive clutch assembly. The assembly consists of a clutch plate, pressure plate, and a diaphragm spring. The materials chosen for the three parts were structural steel for a clutch plate, cast iron GS-70-02 for the pressure plate, and spring steel for diaphragm spring. A static structural analysis in each section was performed. Finite element analysis was carried out in the initial process, the solver, and the final process. The uniform wear theory was used for the analysis process. Solidworks software and ANSYS software was used to design and analyse structures. The results revealed that the design of the friction clutch assembly was safe.

Abdullah [19] investigated the stresses and deformations of dry friction clutch systems. In order to study both stresses and deformations in the clutch, the finite element method was used. The components analysed were pressure plate, clutch disk, and flywheel. There were five algorithms used for surface-contact types: the penalty method, augmented Lagrange, Lagrange multiplier on contact usual and penalty on a tangent, pure Lagrange multiplier on contact normal and tangent and internal multipoint constraint method. To get the pressure distribution between contact surfaces, the penalty and augmented Lagrangian algorithm was used. ANSYS 13 software has been used for numerical modelling and calculation. The effect of the frequent contact stiffness factor on the distribution of pressure between the contact surface, stress, and deformation was studied. From the study, it was concluded that the penalty method has a sensitivity for the various contact stiffness factor more than the augmented method. It was also concluded that the maximum and minimum values of contact stress occur at an outer disc radius and inner disc radius, respectively.

Narkhede and Varma [20] modelled single circular grooves made on dry friction clutches using CATIA V5 based on Finite Element Methods. The result indicated that maximum torque transmitted with a single circular groove pattern 10.43 % bigger than 23^{o} inclined grooves.

Based on the background that has been described to reduced designing time and cost, this study aimed to compare the stresses on a shaft, spline, friction plate, and spring, which were obtained by mathematical calculations with finite element analysis. The analysis was conducted using ABAQUS software.

2. RESEARCH METHODOLOGY

2.1. Physical problem and Geometry

The single friction plate clutch components designed in the study are shaft, spline, friction plate, and spring. The arrangement of this single friction plate clutch is shown in Figure 1. The shaft in this clutch was made of S30C carbon steel, spline made of S30C carbon steel, friction plate made of alloy steel, and spring made of carbon steel.

The design of the clutch was performed by two methods, namely mathematical calculations and finite element modelling methods using the ABAQUS software. The results obtained by the two methods would be compared to validate.

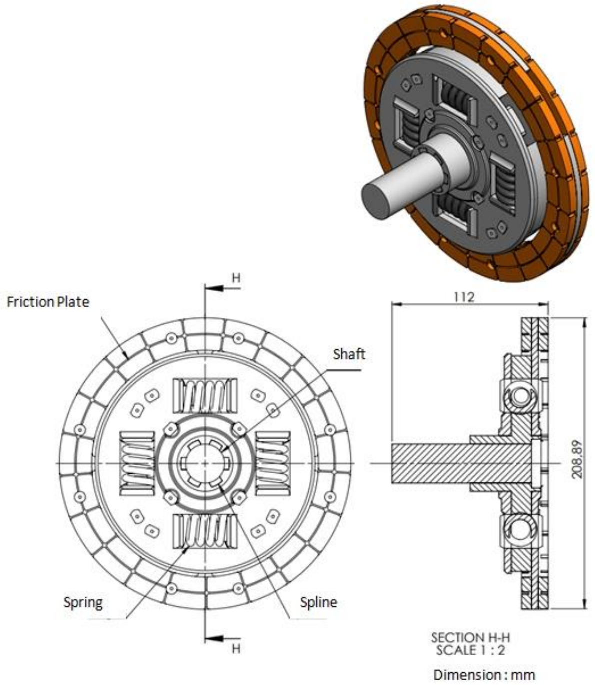

Figure 1. Single Friction Plate Clutch.

The first stage of this research was to do a mathematical calculation of the shaft, the spline, the friction plate, and the spring. Torsion, which was applied on the shaft, was calculated by using equation 1.

$$T = \frac{P \times 60}{2\pi n}, \quad (1)$$

where T is the torque (N.mm), P is the power (Watt), and n is speed (rpm). While force is calculated by using equation 2.

$$F = \frac{T}{r}, \quad (2)$$

where F is the force (N), T is the torque (N.mm), and r is the radius (mm). Furthermore, shear stress is calculated using equation 3.

$$\tau = \frac{F}{A}, \quad (3)$$

where τ is the shear stress (N/mm^2), F is the force (N), and A is the shear surface (mm^2). In this stage, it is also examined the safety of the use of materials that have been selected. The safety check is based on the yield shear stress level.

2.2. Modelling

In the second stage, modelling of the design of a single friction plate clutch in the form of shafts, spline, friction plate, and spring was carried out by using the 2017 Solid works software. Problem analysis was then performed using the ABAQUS 6.14-5 software. Data were entered in the form of mechanical properties of a single friction plate clutch material into the ABAQUS module 6.14-5.

Convergence studies were carried out to determine the number of elements with an acceptable accuracy value in the finite element analysis process. The analysis was carried out by comparing the sizes of different elements. A comparison in simulation processes was performed using the von Mises stress value. The validation stage was conducted by comparing the results of mathematical calculations with the results of the analysis based on the finite element method.

3. RESULTS AND DISCUSSION

Mathematical calculation to get the shear force and shear stress on the shaft, spline, friction plate, and spring components was performed by equations 1, 2, and 3, as written by Khurmi and Gupta [21]. The calculation was given in Table 1. The obtained force was used as input for the finite element analysis method.

Table 1. The m**athematical calculation for the force and shear stress on the shaft, spline, friction plate, and spring**.

No	Component	Force (N)	Shear Stress (N/mm^2)
1	Shaft	8757.964	28.461
2	Spline	1459.661	3.792
3	Friction Plate	3394.733	0.25
4	Spring	306.332	525

In this design process, shaft, spline, friction plate and spring were drawn by Solid works software. The model was then analysed by ABAQUS software. Forces that work on components are shown in Figure 2.

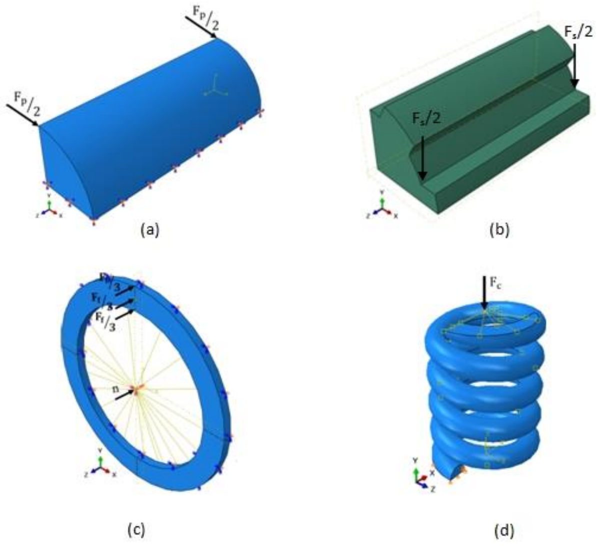

Figure 2. Applied forced at on (a) shaft (b) spline (c) friction plate (d) spring.

Convergence studies were carried out on the simulation process for shaft, spline, friction plate, and spring. The results of the convergence process can be seen in Figure 3.

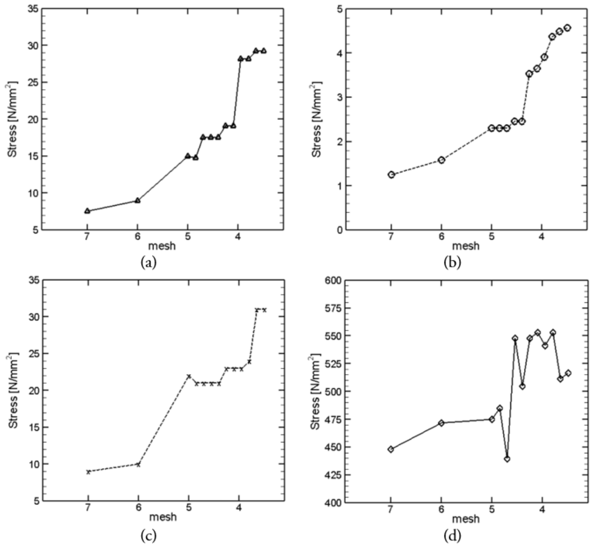

Figure 3. Convergence studies result for shear stress on (a) shaft (b) spline (c) friction plate (d) spring.

A convergence study was carried out on a shaft with a diameter of 28 mm, a length of 50 mm, and a force load of 8757.964 N. Simulations applied mesh sizes of 7, 6, 5, 4.85, 4.7, 4.55, 4.4, 4.25, 4.1, 3.95, 3.8, 3.65, and 3.5. This convergence test shows that mesh sizes of 3.65 and 3.5 have reached convergence (Figure 3a).

In the convergence study on a spline with a diameter of 35 mm, length of 43.988 mm, and the number of pins of 6 pieces, the applied force was 1459.661 N. As previously, simulations applied mesh from coarse to fine with sizes between 7 and 3.5. The test with a mesh size of 3.8 has been convergent, with the results of von-misses stress shown in Figure 3.b.

For friction plate with an outer radius of 104.625 mm, an inner radius of 81.375 mm, and a thickness of 10 mm, the applied force was 3394.733 N. Simulations also applied mesh from coarse to excellent with sizes between 7 and 3.5. In this test, a mesh size of 3.65 was taken because convergence has been reached (Figure 3c).

Finally, convergence study was conducted on the spring with a diameter of 19.508 mm, wire diameter of 4.877 mm, spring length of 31.111 mm and the applied force on each spring of 306.332 N. The mesh was made with sizes of 7, 6, 5, 4.85, 4.7, 4.55, 4.4, 4.25, 4.1, 3.95, 3.8, 3.65, and 3.5. In this test, a 3.5 mesh size has reached convergence (Figure 3d).

The simulation results with Abaqus software is shown in Figure 4. From these results, it can be seen that the maximum von-misses stress that occurs at the shaft, spline, friction plate, and spring were 29.204, 3.872, 0.252, and 516.853 N/mm^2, respectively. Therefore, the material is safe to use because it is still below the yield strength.

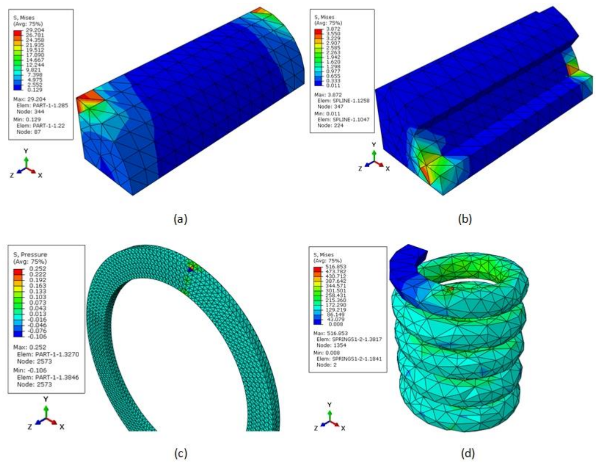

Figure 4. The results of the simulation process on (a) shaft (b) spline (c) friction plate (d) spring.

Deviations from the calculation of shear stress manually with the shear stress simulation results are shown in Table 2. The most significant deviation between manual calculations and simulation results is 2.881%; this deviation is less than 5% and is acceptable [22].

Table 2. Validation.

No	Component	Shear Stress		Deviation (%)
		Mathematical Calculation (N/mm^2)	Finite Element Analysis Result (N/mm^2)	
1	Shaft	28.461	29.204	2.61
2	Spline	3.792	3.872	2.066
3	Friction Plate	0.25	0.252	0.8
4	Spring	525	516.853	1.552

4. CONCLUSION

Based on the results of the study, the analysis of research results between mathematical calculations with the simulation process on the components of a single friction plate clutch can be concluded as follows.

The mathematical calculations result of the shear stress of the shaft, the spline, the friction plate, and the spring are 28.461, 3.792, 0.25, and 525 N/mm^2, respectively. At the same time, the finite element analysis results of the maximum von-misses stress that occurs at the shaft, spline, friction plate, and spring are 29.204, 3.872, 0.252, and 516.853 N/mm^2, respectively.

Results between mathematical calculations and finite element analysis in the design of a single friction plate clutch are valid and acceptable because the maximum deviation is 2.881%, with an acceptable deviation limit <5%.

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