Design and Finite Element Analysis of an Automotive Clutch Assembly

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Abstract

The purpose of a clutch is to initiate motion or increase the velocity of a body generally by transferring kinetic energy from another moving body. The mass being accelerated is generally a rotating inertial body. The present paper deals with designing a friction clutch assembly using Solid Works Office Premium software. The assembly comprises of the clutch plate, the pressure plate and a diaphragm spring. Static structural analysis was done using ANSYS software. The plots for equivalent stress, total deformation and factor of safety were obtained and the design was continuously optimized till a safe design was obtained. Uniform wear theory was used for the analysis. The material assignment is as follows: clutch plate- structural steel, pressure plate- cast iron GS-70-02 and diaphragm spring- spring steel. The friction material assumed is molded asbestos opposing cast iron/steel surface.

Keywords: Design, FE Analysis, Automotive clutch plate, Diaphragm plate, Clutch assembly.

1. Introduction

The finite element analysis is the most widely accepted computational tool in engineering analysis. Through solid modelling, the component is described to the computer and this description affords sufficient geometric data for construction of mesh for finite element modelling. Purohit and Sagar (2005-2006) have done the finite element analysis of Al-SiC\textsubscript{p} composite poppet valve guides and valve seat inserts. Purohit et. al. (2010) have done the linear static analysis of motorcycle piston.

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Gao Lian-hua, Jia Xiao-Ping (1993) reported in their experiment that the main clutch of heavy vehicles is the basic execution component, which realizes the vehicle to start, shift, move and stop. Separating the main clutch will prevent the transmission device and the engine from being damaged by too heavy load during the violent change of the load over the heavy vehicle.

In the present work a clutch assembly has been designed in the Solid Works Office Premium Software. Thereafter, static structural analysis of each part was done. The assembly consists of a clutch plate, a pressure plate and a diaphragm spring as explained below:

1.1 Clutch

A Clutch is a machine member used to connect the driving shaft to a driven shaft, so that the driven shaft may be started or stopped at any time, without stopping the driving shaft. A clutch thus provides an interruptible connection between two rotating shafts. Clutches allow a high inertia load to be started with a small power. Clutches are also used extensively in production machinery of all types.

1.2 Pressure Plate

Pressure plate is a cast iron plate that provides a pivot fulcrum for the diaphragm spring, a friction surface for the disc and a mounting surface for the drive straps. Pressure plates are round, metallic devices containing springs and fingers, or levers and controlled by the release fork connected to the shifter. All of the clutch components are enclosed in the bell housing of the transmission, between the rear of the engine and the front of the gearbox. The pressure plate pushes the clutch disc against the constantly spinning engine flywheel. The clutch disc, therefore, is either stationary or rotating at the same speed as the flywheel. Friction material, similar to that found on brake pads and brake drums, causes the clutch disc to spin at the same speed as the engine flywheel. It is this friction between clutch disc and flywheel that allows the engine torque to drive the wheels.

There are three major types of pressure plates: (1) The Long style which is used mainly for drag racing. (2) The Borg & Beck which is more robust materials (3) The diaphragm pressure plate is best suited for street use and is, therefore, the most common type found on later-model automobiles. It contains a single Bellville-style spring that applies a more even load from clutch plate to flywheel. Because the single-spring diaphragm is more effective “over-center”, there is also less effort needed by the driver to hold the clutch pedal in the depressed position at a stop. In the present design a diaphragm pressure plate has been selected.

1.3 Diaphragm Spring

V.B. Bhandari (2008) explained in his experiment that Diaphragm spring is a flat, spring-steel disc compressed between the cover and pressure plate that, when pushed by the release bearing, engages and disengages the clutch. The diaphragm spring is a single thin sheet of metal which yields when pressure is applied to it. When pressure is removed the metal springs back to its original shape. The centre portion of the diaphragm spring is slit into numerous fingers that act as release levers. When the clutch assembly rotates with the engine these weights are flung outwards by centrifugal forces and cause the levers to press against the pressure plate. During disengagement of the clutch the fingers are moved forward by the release bearing. The spring pivots over the fulcrum ring and its outer rim moves away from the flywheel. The retracting spring pulls the pressure plate away from the clutch plate thus disengaging the clutch.

When the driver steps on the clutch pedal, a number of springs in the pressure plate are compressed by multiple (most often three) fingers. This compression of the spring(s) pulls the pressure plate and the clutch disc away from the flywheel and thus prevents the clutch disc from rotating. When the clutch disc is stationary, the driver can shift into the proper gear and release the clutch pedal. When the pedal is let up, the fingers in the pressure plate release
their grip and the spring(s) expand to push the pressure plate into the clutch disc, thereby engaging the flywheel. This release process is often called the “clamp load”.

It shall be noted that in Diaphragm Springs, Residual stress occurs in either front or rear surface, or both surfaces used for automobile clutches due to shot-peening. Studies reveal that the residual stress remarkably affects the load–deflection \((P-\delta)\) curve of diaphragm springs.

1.4 Clutch Wear

V.K. Jadon and Suresh Verma (2007) said that it is possible to predict clutch wear. The front surface temperature of a clutch pressure plate is studied for clutch wear prediction. A combined deterministic plus stochastic modeling approach is used to fit the front surface temperature data.

2. Static Structural Analysis

2.1 Equivalent Stress (Von Mises Stress)

While the Equivalent Stress at a point does not uniquely define the state of stress at that point, it provides adequate information to assess the safety of the design for many ductile materials. Unlike stress components, the Equivalent Stress has no direction. It is fully defined by magnitude with stress units. To calculate the factors of safety at different points, the Von Mises Yield Criterion is used, which states that a material starts to yield at a point when the Equivalent Stress reaches the yield strength of the material.

Equivalent stress is related to the principal stresses by the equation:

\[
(S1-S2)^2 + (S2-S3)^2 + (S3-S1)^2 = 2Se^2
\]  

(1)

Equivalent stress is often used in design work because it allows any arbitrary three-dimensional stress state to be represented as a single positive stress value. Equivalent stress is part of the maximum equivalent stress failure theory used to predict yielding in a ductile material.

2.2 Total Deformation

Physical Deformations can be calculated on and inside a part or an assembly. Fixed supports prevent Deformation; locations without a fixed support usually experience deformation relative to the original location. Deformation is calculated relative to the part or assembly in world coordinate system.

\[
U^2 = (U_x^2 + U_y^2 + U_z^2)
\]  

(2)

\(U_x, U_y\) and \(U_z\) are the three components of Deformation.

2.3 Stress Tool (Factor of Safety)

The following stress tools are available in the solution object:

1) Maximum Equivalent Stress Safety Tool
2) Maximum Shear Stress Safety Tool
3) Mohr-Coulomb Stress Safety Tool
4) Maximum Tensile Stress Safety Tool
In the present analysis Maximum Equivalent Stress Safety Tool has been used. The Maximum Equivalent Stress Safety tool is based on the maximum equivalent stress failure theory for ductile materials, also referred to as the Von Mises-Hencky theory, octahedral shear stress theory, or maximum distortion (or shear strain) energy theory. Out of the four failure theories supported by Simulation, this theory is generally considered as the most appropriate for ductile materials such as aluminium, brass and steel.

The theory states that a particular combination of principal stresses cause failure if the maximum equivalent stress in a structure equals or exceeds a specific stress limit:

\[ S_e \geq S_{\text{limit}} \]

Expressing the theory as a design goal:

\[ S_e / S_{\text{limit}} < 1 \]

If failure is defined by material yielding, it follows that the design goal is to limit the maximum equivalent stress to be less than the yield strength of the material:

\[ S_e / S_y < 1 \]

An alternate but less common definition states that fracturing occurs when the maximum equivalent stress reaches or exceeds the ultimate strength of the material:

\[ S_e / S_u < 1 \]

Safety Factor

\[ F_s = S_{\text{limit}} / S_e. \]

Using the Equivalent Stress (Von Mises Stress), the Total Deformation and the Stress Tools; it was determined whether the parts would yield under loading conditions or not. The design was continuously optimized during the process.

2.4 Design Considerations

A clutch of good design must have adequate torque capacity, ability to withstand and dissipate heat and should have a long life. The clutch must have positive release, smooth engagement, low operating force and ease of repair. To permit easy engagement and to prevent excessive wear during the engagement period the facing should be flexible and the largest possible area should be in contact during engagement. To overcome the inertia of the driven parts, when starting, clutches should be designed for overload capacities of 75 to 100 percent.

3. Finite Element Analysis of Clutch Assembly

The finite element analysis of clutch assembly was carried out in the following steps:
1) Calculation of the dimensions of the clutch assembly
2) Material selection for the clutch plate, pressure plate and diaphragm spring
3) Creating a three-dimensional model of clutch assembly (clutch plate, pressure plate and diaphragm spring) in Solid Works Office Premium Software
4) Exporting the model to ANSYS for simulation and dividing it into small elements
5) Defining the material property and geometry data
6) Defining the Environment (a combination of loads and supports)
7) Submitting the Model to the ANSYS solver; Obtaining Solution (Equivalent von-Mises stress, Total Deformation and Stress Tool) and evaluation of the results

3.1 Calculation of the dimensions of clutch assembly

First of all the values of coefficient of friction and pressure for clutch were selected from Table 1.

It shall be noted that for a friction clutch, during its life time, changes in the friction materials’ topography occur. Gao Lian-hua, Jia Xiao-Ping, 1993 stated that these changes will influence the friction characteristics of the clutch, and therefore affect the anti-shudder performance of the transmission system.

| Contact Surfaces | Coefficient of friction, μ | Max Temp, °C | Bearing Pressure, N/mm² | Comment                           |
|------------------|---------------------------|--------------|-------------------------|----------------------------------|
| Wearing surface  |                           |              |                         |                                  |
| Opposing surface |                           | Wet          | Dry                     |                                  |
| Molded Asbestos  |                           | 0.08-0.12    | 0.2-0.5                 | 260                              | 0.34-0.98 Wide field of applications. |

Selecting, Coefficient of friction μ = 0.2857 and
Bearing Pressure (Pa) = 0.7 N/mm².
Take:
Do = 180 (Keeping Do constant and calculating the values of other dimensions)

The ratio of inner to outer diameter for maximum torque transmission:
X = (Di/Do) = 0.48; for p = constant.
X = (Di/Do) = 0.577; for pr = constant.
Where:
Di = Inner diameter
Do = Outer diameter

Assuming uniform wear theory:
Therefore; Di = Do*0.577
 ⇒ Di = 180*0.577
 ⇒ Di = 103.86

Fa = π*a*Di*(Do-Di)/2
 ⇒ Fa = 3.14*0.7*103.86*(180-103.86)/2
 ⇒ Fa = 8695.190 N

Mt = n*μ*Fa*(Dm)/2
 ⇒ Mt = 2*0.2857*8695.190*((180+103.86)/2)/2
 ⇒ Mt = 352.6N-meter
 ⇒ Mt = 352600 N-mm

d = ((16*Mt)/(π*td)) 1/3
 ⇒ d = ((16*352600)/(3.14*40)) 1/3
 ⇒ d = 35.54 mm
3.2 Material Selection

The following materials were selected for finite element analysis:

1) Clutch Plate: Structural Steel.

2) Pressure Plate: Cast Iron GS-70-02.

3) Diaphragm Spring: Spring Steel.

The table 2 shows the mechanical properties of the above three selected materials.

| S. No. | Material          | Elastic Modulus (Pa) | Poisson Ratio | Coefficient of Thermal Expansion | Density kg/m³ |
|-------|-------------------|----------------------|---------------|----------------------------------|---------------|
| 1.    | Structural Steel  | $2.0 \times 10^{11}$ | 0.3           | $1.2 \times 10^{-5}/ °C$         | 7850          |
| 2.    | Cast Iron GS-70-02| $1.8 \times 10^{11}$ | 0.28          | $1.229 \times 10^{-4}/ °C$       | 7400          |
| 3.    | Spring Steel      | $2.1 \times 10^{11}$ | 0.3           | $3.26 \times 10^{-6}/ °C$        | 7850          |

3.3 Development of 3-D model for clutch assembly in Solid Works Software

3.3.1. Clutch Plate

It is an assembly formed from: a Plate, Friction Lining and a Splined Hub.

1) Plate: The features used in Solid Works are Extrude, Cut-Extrude, Circular Pattern and Fillets.

2) Friction lining: The features used in Solid Works are Extrude, Cut-Extrude.

3) Splined Hub: The features used in Solid Works are Extrude, Circular Pattern.

Clutch Plate Assembly: Mate feature in Solid Works was used to join the three components.

3.3.2. Pressure Plate

It is mated with friction lining and the features used in Solid Works are Assembly Mates, Loft (extending over 4 planes), Cut-Loft (extending over 3 planes) Cut-Extrude.

3.3.3. Diaphragm Spring

The features used in Solid Works are Loft (extending over 6 planes), Shell, Cut-Extrude, Circular pattern, Extrude.

The figure 1 shows the finite element model of the clutch assembly (Exploded View):
3.4 Finite element analysis of each part of clutch assembly using ANSYS software

3.4.1 Clutch Plate

A Mesh was created (Dividing the model into small elements). Material property and geometry data were defined (as per the section 3.1 and 3.2). The Environment (a combination of loads and supports) was defined as follows:

Loads: Moment: 176.3 N-m (each side); Pressure: 0.7 MPa.

The Model was submitted to the ANSYS solver and the solutions for the Equivalent von-Mises stress, Total Deformation and Stress Tool were obtained. The figure 2 shows the distribution of equivalent von-Mises stress over the clutch plate. The figure 3 shows the distribution of total deformation over the clutch plate. The figure 4 shows the distribution of Factor of Safety (Stress Tool) over the clutch plate. The figure 4 shows that the minimum factor of safety for the clutch plate is greater than 10.
Fig. 2 The equivalent von-Mises stress plot for the clutch plate

Fig. 3. The Total Deformation plot for the clutch plate
3.4.2 Pressure Plate

The model of the pressure plate was meshed. The material property and geometry data were defined as per section 3.1 and 3.2. The Environment (a combination of loads and supports) was defined as follows:

Loads: Moment = 356.2 N-m
Pressure 1 = 0.7 MPa; Pressure 2 = 0.75 MPa.

(Pressure 1 acts on the back surface of the pressure plate; it is the reaction pressure from the clutch plate, and Pressure 2 acts on the front portion of the pressure plate facing the diaphragm spring)

The Model was submitted to the ANSYS solver and solutions were obtained (Equivalent von-Mises stress, Total Deformation and Stress Tool). The figure 5 shows the distribution of equivalent von-Mises stress over the entire pressure plate. The figure 6 shows the distribution of total deformation over the entire pressure plate. The figure 7 shows the distribution of factor of safety (Stress Tool) over the entire pressure plate. The figure 7 shows that the minimum factor of safety for the pressure plate is 1.797.

Fig. 4. The Factor of Safety (Stress Tool) plot for the clutch plate
Fig. 5. The equivalent von-Mises stress plot for the pressure plate

Fig. 6. The total deformation plot for the pressure plate
3.4.3 Diaphragm Spring

The model of diaphragm spring was meshed. The material property and geometry data were defined as per section 3.1 and 3.2. The Environment was defined as follows:

Loads: Moment = 356.2 N-m; Force = 10 N.

The Model was submitted to the ANSYS solver and Solutions for equivalent von-Mises stress, Total Deformation and Stress Tool were obtained. The figure 8. shows the distribution of equivalent von-Mises stress over the entire diaphragm spring. The figure 9 shows the distribution of total deformation over the entire diaphragm spring. The figure 10 shows the distribution of factor of safety (Stress Tool) over the entire diaphragm spring. The figure 10 shows that the minimum factor of safety for the diaphragm spring is 2.1657.
Fig. 8. The equivalent von-Mises stress plot for the diaphragm spring.

Fig. 9. The total deformation plot for the diaphragm spring.
Conclusions

In the present work a friction clutch assembly was designed and a model of the same was created in Solid Works Office Premium Software. It consist of three parts viz. clutch plate, pressure plate and diaphragm spring. Finite element analysis was performed in ANSYS software. The finite element analysis was carried out in three steps: Pre-processing, Solving and Post processing. The plots for Equivalent von-Mises stress, total deformation and stress tool (factor of safety) were calculated and analyzed. The finite element analysis showed that the designed friction clutch assembly is safe.

References

Gao Lian-hua, Jia Xiao-Ping, 1993. The Structure of a Tank EM. Beijing: Academy of Armored Force Engineering Press. http://www.eng-tips.com/viewthread.cfm?qid=188185&page=31
R. Purohit and R. Sagar, 2005. Finite element Analysis of Al-SiC$_p$ composite Poppet Valve Guides, International Mobility Engineering Congress and Exposition, SAE INDIA, Chennai, October 23-25, 2005.
R. Purohit and R. Sagar, 2006. Finite element Analysis of Al-SiC$_p$ composite Valve Seat Inserts, Proceedings of National Conference on Advances in Mechanical Engineering, January 20-21, 2006, Jamia Millia Islamia, New Delhi.
Rajesh Purohit, Gautam Batra, Bikas Ranjan Sukla, and Prateek Dudeja, 2010. Design And Linear Static Analysis Of Motorcycle Piston, International Journal of Industrial Engineering And Technology (IJIET), Volume 2, Number 1, 271-278.
V.B. Bhandari, 2008. Design of machine elements, second edition, Tata Mc. Graw Hill Publishing Company.
V.K. Jadon and Suresh Verma, 2007. Machine Design Data Book, Second edition, I.K. International Publishing House.