STRUCTURAL ANALYSES OF AN AUTOMOTIVE DRY CLUTCH WITH QUARTER ASSEMBLY MODEL APPROACH

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Abstract
This study aim calculating stress distribution, determination of the spring force with release travel and calculating releasing displacement on clutch assembly by using finite element method. Quarter clutch model is used for those analyses. Solid model of clutch assembly is performed by Solidworks 2016® and structural analysis is achieved by Ansys Workbench 15®. Structural analysis is performed in four steps which their first, second and third steps are related with assembly operation and fourth step is simulate spring deformation of clutch assembly. Spring forces are calculated with quarter clutch assembly model. Numerical results are compared with experimental result of diaphragm spring for validation of finite element analysis. Embossed diaphragm spring design is examined to reduce stress on clutch parts. Finite element results show the embossed spring design effect the clearance between pressure plate and clutch disc.

Key words: *Automotive dry clutch; quarter model; diaphragm spring; finite element method*

INTRODUCTION

Automotive dry clutches which are also named friction clutches, actuated externally by internal combustion engine to transmit torque from engine to gearbox with friction forces. External actuation performed via pushing clutch pedal. Kuralay (2008) reported of elastic deformation on diaphragm spring occurs during disengagement that produce release forces between pressure plate and friction disc of clutch. Clutch working operation is defined by reaction forces occurred by deformation of diaphragm spring. By applying preload, conical diaphragm spring is almost flattened. Clutch release takes place by force exerted by pressure bearing from diaphragm spring's flattened position. In power transmission, periphery of diaphragm spring applies pressure to pressure plate. This pressure is generated by connection between pressure plate and clutch via strap links.

Diaphragm spring's cone angle, width and other dimensions determine the values of reaction forces and load-deflection curve characteristic. Equivalent stress distributions and deformations of clutch assembly are connected with diaphragm spring's force-displacement behavior. Therefore, in the literature Topaç (2009) and Li-Jun (2008) are studied the effects of diaphragm springs' force-displacement behavior are studied by Pisaturo (2016) comprehensively. Other investigations are focused on one clutch component individually by Shukla (2016), and clutch assembly model by Purohit (2014) to determine structural behavior of clutch system which is consisted the determination of stress distribution and elastic deformation.

In the studies, structural behavior of vehicle clutches are examined by Vitnor (2016) with finite element (FE) method which is constructed to cover full assembly model. In this study, quarter assembly model is used to save time. Besides other literature works, preload conditions are included in FE analysis and structural behavior of clutch are investigated for assembly operation also.

Embossed diaphragm spring design is developed by Danev (2014) instead of diaphragm springs used in conventional vehicle clutches. Stresses and deformations of embossed diaphragm springs are examined comparatively with conventional ones. Evaluation of the improvement of friction clutch function and diaphragm spring stiffness are implemented.

MATERIALS AND METHODS

Quarter model of assembly is used for FE analysis instead of full clutch model. Quarter model was separated symmetrically which strap link and contact surface of release fork on release bearing assembly is located in the middle of model. Solid model of clutch assembly and their components are shown in figure 1. In order to determine the structural behaviour during the preloading and releasing operations a FE model has been implemented by using a commercial software named Ansys Workbench 16®. Proper mesh elements as Solid 92, Solid 95 and Solid 45 were used to simulate the quasi-static testing. Totally, 110709 elements and 219130 nodes of mesh were used on quarter model in the FE analysis. Body sizing on diaphragm spring, pressure plate and strap link, face sizing on pressure plate bottom surface and contact surfaces of diaphragm springs were applied for the accuracy of the results.

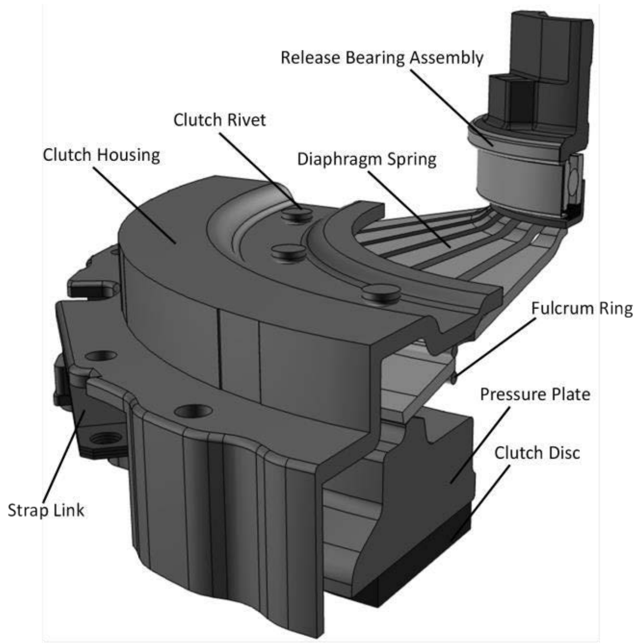

Fig. 1. Quarter Clutch Assembly Model

Diaphragm springs are designed in two different types as conventional (non-embossed) and embossed. This types of springs are separately applied on quarter clutch model for finite element analysis. A slice of embossed diaphragm spring is illustrated in Fig. 2 with emboss location and characterization dimensions. As shown in the Fig. 2, depth of emboss is 3 mm and representing λ is width, δ is length of emboss, ε is the distance from outside diameter to emboss starting location. Embossed model dimensions present as; λ is 3 mm, δ is 29.5 mm and ε is 38 mm.

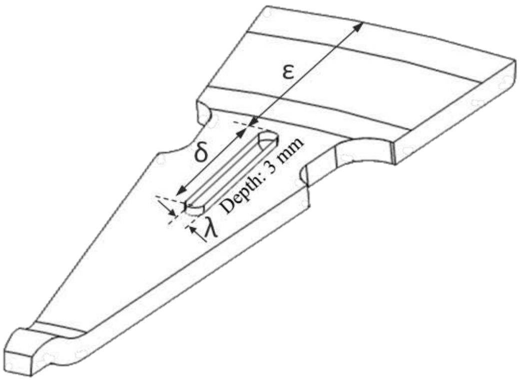

Fig. 2. Embossed Diaphragm Spring Dimensions

Diaphragm spring is manufactured from 50CrV4 steel alloy. Tension tests are implemented by test rig for four 50CrV4 steel alloy specimen. Average of test data was used in FE analysis. For plastic deformation, material's stress-strain diagram was determined by the test results to observing accurately elastoplastic behavior of diaphragm spring in FE method. Release bearing housing was produced GGG70 ductile cast iron. Bearing material is defined as SUJ2. Remaining clutch members' materials are accepted as structural steel alloy which hardening and hot tempered operations are implemented on them. Mechanical properties of materials which including young's modulus (E), poisson's ratio (ν), yield stress (S_y), tensile stress (S_{ut}) and density (ρ) are given in Table 1.

Tab.1. Clutch materials and properties

Material	E [GPa]	ν -	S_y [MPa]	S_{ut} [MPa]	ρ [kg/m^3]
Structural Steel	200	0.3	300	460	7850
50CrV4	227.5	0.3	1340	1370	7850
GGG70	176	0.275	420	700	7200
SUJ2	208	0.3	1370	1570	7830

Finite element method is used for understanding structural features of the clutch components. An advantage of FE method is that it can solve the mechanical problems with arbitrary structures and boundary conditions. Boundary conditions are taken as frictionless support at sections of quarter assembly model in FE method. Bolt holes of outside clutch housing and outside surfaces of intersection between clutch housing and flywheel are taken as fixed support. In clutch modeling, relations between components are classified as frictionless and frictional. To shorten analyze time, some of undersize contact faces, contacts are accepted as frictionless contact. Clutch housing-fulcrum ring, fulcrum ring-clutch rivets, diaphragm spring-fulcrum ring, diaphragm spring-pressure plate and strap link-rivets areas are assumed as frictionless contact. Pressure plate-strap link, strap link-rivets connections are defined as frictional contact. There is frictional contact between inner plates of strap link. In frictional contact surfaces, coefficient of friction is taken as 0.15 for metal-metal contact.

In Fig. 3, quarter assembly model of clutch components and analysis inputs of preloading and releasing displacements are presented. FE analysis is evaluated in four steps as shown in the graphic. First step represents preload operation for diaphragm spring which is applied on pressure plate. Preload operation of diaphragm spring actuates 6 mm from outer surface of it to the opposite direction of flywheel. Second step represents fixing operation between cover and pressure plate by using strap link connection. Strap link (green) is pressed 16.8 mm after first step to cover and bolted. Third and the last step is related with the releasing operation of bearing assembly. In third step, release bearing is travelled to new location of diaphragm spring contact surface with any resistant because of the deflection of the diaphragm spring after preload operation. Release bearing displacement is 20 mm until it reaches to diaphragm spring contact. Last step shows the loading of diaphragm spring for releasing operation.

The reason of separation third and fourth steps is to prevent connection fails with exact contact forming and investigation of releasing process individually.

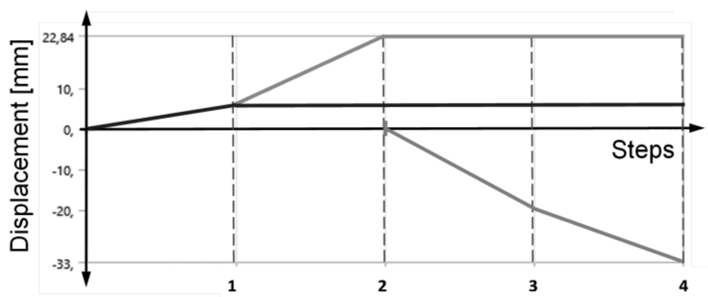

Fig. 3. Inputs of Clutch Model Components (Upper Line: Strap Link, Middle Line: Pressure Plate, Bottom Line: Release Bearing)

Force characteristic curve of conventional diaphragm spring is achieved by using force probe on lower fulcrum ring after finite element analysis was solved. Experimental and finite element results are good agreement especially in preloading time. Comparison of conventional diaphragm spring characteristics by experimental and numerical method is defined validation for the study.
Release bearing assembly was taking into consider individually. Reaction forces on the contact surface of diaphragm spring was determined by force probe in FE analysis. Reaction forces acts on release bearing assembly occurs during the last step which represents releasing operation.

RESULTS AND DISCUSSION

Except from the release bearing assembly, rest of components evaluated in quarter clutch model. Maximum stress on diaphragm spring reach at the top level of stress value in first step of FE analysis. Maximum stress level is reached in the middle of first step time. Maximum stress on diaphragm spring is shown in Figure 4 for both conventional type and embossed type.

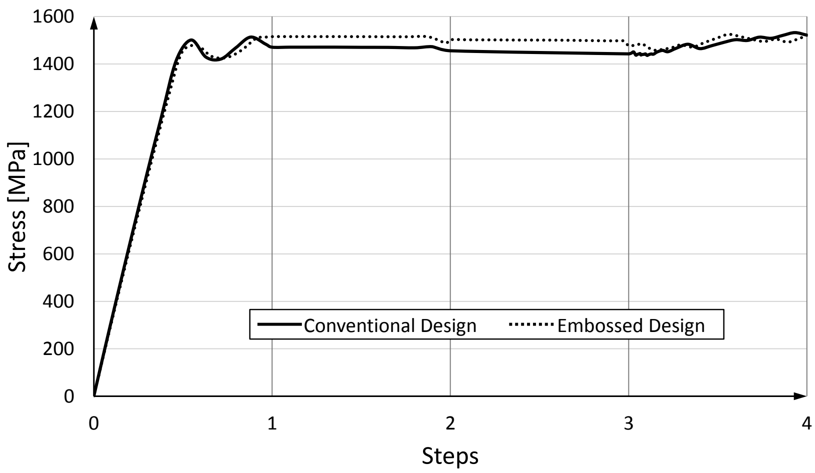

Fig. 4. Maximum Equivalent Stress on Diaphragm Spring

Preload operation causes increasing maximum stress of diaphragm spring on first step. Yield stress of diaphragm spring material is exceeded during preloading in up to 1370 MPa. Plastic deformation on diaphragm spring is occurred in first step. Until the last times of first step, maximum stresses of conventional and embossed spring types are similar. Strap link connection and release bearing free movement do not affect the stress in second and third step. Similar characteristics are occurred on springs in releasing operation. It is obvious that, equivalent stress are not tremendously changed on diaphragm springs at releasing. After the separation of clutch disc from pressure plate at the end of last step, stress distribution of diaphragm springs shown in the Figure 5.

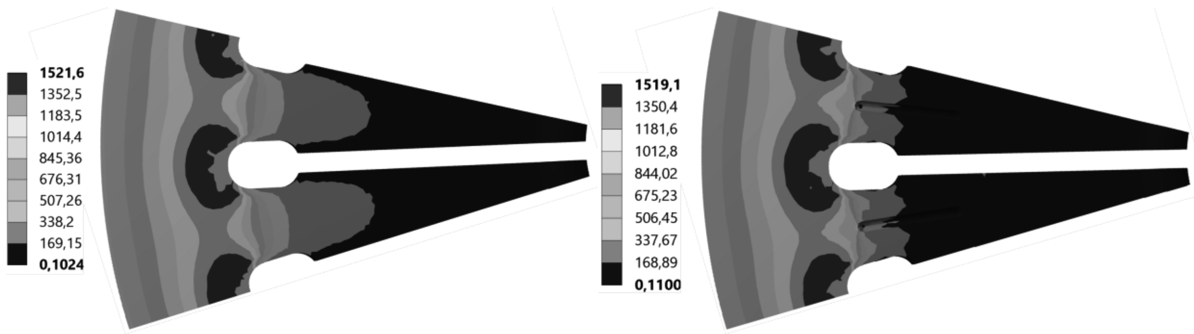

Fig. 5. Stress Distributions of Conventional (left) and Embossed (right) Diaphragm Springs at the end of releasing

Conventional diaphragm spring has maximum 1521.6 MPa and embossed diaphragm spring has 1519.1 MPa maximum stress. Stress distribution shows similar in both types. The advantage of embossed type diaphragm spring is having less stress on the spring fingers relatively.
Clutch housing is an important component of clutch assembly which less deformation and stress are desired on it for long service life without any failure such as cranking or fatigue. Maximum stress on clutch housing is shown in Figure 6. Clutch model with conventional type was always caused more stress on it. In preload operation stress was reached up to 200 MPa in conventional type. At the end of strap link connection on clutch housing, equivalent stress was reached about 295 MPa in conventional design and 270 MPa in embossed design. Release bearing motion that is reverse direction of preloading and strap link connection effects on decreasing stress in last step. It is clear that embossed design is useful for clutch housing because of less stress occurred.

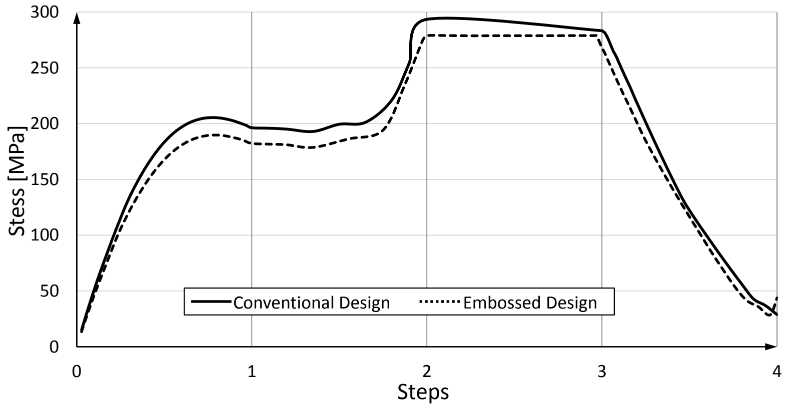

Fig. 6. Maximum Equivalent Stress on Clutch Housing

Strap link also is exposed the situation of exceeding yield stress and deforming plastic. Reasonable plastic deformations can occurred on trap link for connection of housing and pressure plate.
Fulcrum ring holds diaphragm spring with clutch cover. The deformation of diaphragm spring occurs due to fulcrum ring acting as support. Especially in releasing operation, compression stresses occur on fulcrum ring. Maximum stress on fulcrum ring is shown in Figure 7.

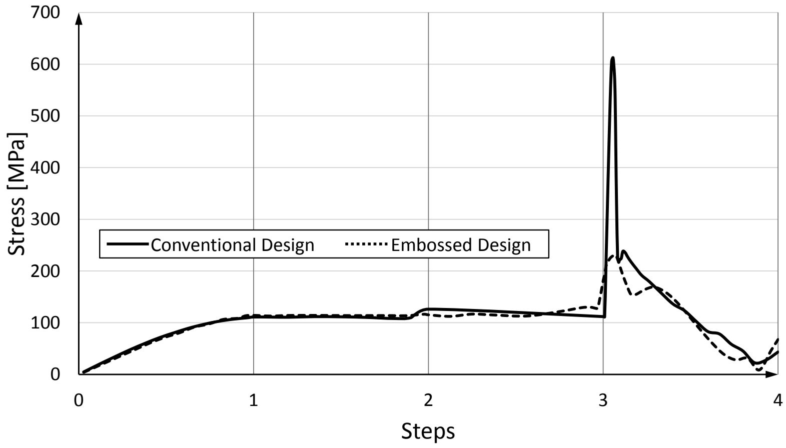

Fig. 7. Maximum Equivalent Stress on Fulcrum Ring

After solution of the analysis steps, disengagement of clutch was simulated by using FE method. Disengagement deflection means clearance between pressure plate and clutch disc on clutch system. End of the third step time represents engagement of clutch by achieving preloading and assembly operation. Clearance characteristics changed linearly during the disengagement. Pressure plate and clutch disc have 6.5 mm displacement until engagement was achieved. Deformations of quarter model of clutch system was assumed zero for initial condition of releasing at the end of third step to calculate releasing clearance between pressure plate and clutch disc. After finishing the solution time pressure plate deflection 9.10 mm for embossed and 8.99 mm for conventional diaphragm spring designs. Deflection difference between pressure plate deflections at the end of fourth step and 6.5 mm initial condition of preloading is defined clearance.

CONCLUSIONS

In this study, structural behavior of the automotive clutch system simulated during both preload operation for assembly and releasing operation. Load-deflection curves of conventional diaphragm spring was achieved by FE method and it was compared with the experimental results which we can assume that as validation for the study. Full model of release bearing assembly was investigated individually. Reaction forces on the contact surface that was occurred during fourth step time against diaphragm spring deformation, was used input force. Maximum stress on release bearing assembly is in the safe area for clutch assembly with conventional diaphragm spring. Simulation of clutch system was implemented for assembly and operation times in four analysis steps. FE results indicate that using embossed diaphragm spring in clutch assembly was improved maximum stress occurred on clutch housing and fulcrum ring. Emboss application was caused increasing on diaphragm spring stiffness. Releasing clearance was determined for two types of spring alternatives. It was calculated 2.99 mm for using conventional diaphragm spring. Emboss effect was increased the clearance up to 3.10 mm. So it is definitely clear that pressure plate clearance can be increased by using embossed diaphragm spring in clutch system. Also this study presents an alternative simulation approach that includes all components of assembly in quarter model for clutch systems by using FE method.

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