Influence of the Thermal Parameters and the Structural Parameters on the Performance of Clutch Pressure Plate

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Abstract. The clutch pressure plate was easy to produce high temperature and axial thermal deformation under the extreme operation conditions, which results in clutch ablation, torque transmission capacity /slip faults. In this paper, a new channel clutch pressure plate was proposed that set a radial cooling channels and axial cooling through holes on the traditional pressure plates. Based on the finite element modeling and analysis of the new pressure plate, the influence of the thermal parameters (such as ambient temperature, convective heat transfer coefficient of the friction surface and the non-friction surfaces) and structural parameters (such as the width and height of the radial cooling channels, the diameter of the axial cooling through holes, etc.) on the temperature field and deformation field of new pressure plate were obtained. The results show that the effect of the thermal parameters on the performance of the new pressure plate was not obvious, but the influence of the structural parameters on the thermal deformation of the new pressure plate was significant. Compared to the performance of the original pressure plate, the performance of the new scheme has been improved significantly.

Introduction

Clutch is an important part of automotive transmission, and the pressure plate is one of the main parts of the clutch. During the automobile starting, the clutch pressure plate and the friction plate realize torque transmission through relative sliding. In the process of clutch engagement, the heat generated by friction will rapidly raise the temperature of the pressure plate, thereby accelerating the abrasion of pressure plate. On the other hand, the thermal deformation caused by temperature rise will reduce the friction area between the pressure plate and the frictional plate which eventually results in incomplete clutch release [1]. Especially for the large-scale construction vehicles such as heavy-duty trucks, due to bad road conditions, the distribution of temperature field and deformation field is more complex and the peak value of the temperature and deformation of the press plate is higher; the clutch pressure plate is prone to cases such as erosion, cracking, etc., resulting in early failure [2].

For the above cases, in this paper, a new channel clutch pressure plate is proposed, and namely, the radial cooling channel and axial thermal through-hole are set in the traditional structure of the pressure plate. The design has won the authorization of national patent for utility models (A channel clutch pressure plate, ZL201510049547.5). To explore the performance of channel pressure plate and its influencing factors, this paper starts with the thermal parameters (including ambient temperature, convective heat transfer coefficient of pressure plate friction surface and non- abrasive surface, etc.) and structural parameters (including radial cooling channel width and height, and axial thermal through-hole diameter, etc.), making thermal-structure coupling analysis of the pressure plate, gaining influence law of the thermal parameters and structural parameters on the temperature field and deformation field. The results show that the thermal parameters have little effect on the working performance of the new pressure plate, and structural parameters have a greater impact on the thermal deformation amount of the new pressure plate. Compared to the original pressure plate program, the new pressure plate has significantly improved working performance.

ANSYS sensitivity analysis based on Spearman's rank correlation coefficient

Assuming that the sensitivity of structural response y (for example, the maximum displacement) to the structural parameters x_1, x_2, ..., x_m (for example, m is cross-sectional area of rod piece) is examined, firstly, the probability distribution function of each specified structural parameter is x_1, x_2, ..., x_m, and subsequently, in stochastic simulation, the value distribution of each structural parameter is based on its probability distribution function. Supposed that n times of stochastic simulation calculation are conducted to obtain n structural response values of y_1, y_2, ..., y_n. Among them, the structural response of i-th simulation operation is y_i, and structural parameters are x_{1i}, x_{2i}, ..., x_{mi}, i = 1, 2, ..., n.

The following m data pairs are constituted of sample values of x_{i1}, x_{i2}, ..., x_{in} for the j-th (j = 1,2, ..., m) structural parameter in the n-th stochastic simulation calculations and response sample values of y_1, y_2, ..., y_n for operational structure in the n-th stochastic simulation:

$$\begin{Bmatrix} X_{j1} \\ y_1 \end{Bmatrix}, \begin{Bmatrix} X_{j2} \\ y_2 \end{Bmatrix}, \ldots \begin{Bmatrix} X_{jn} \\ y_n \end{Bmatrix}, j = 1,2, \ldots, m$$

For each data pair, its Spearman's rank correlation coefficient r_{sj} (j = 1,2, ..., m) is figured out.

R_{sj} reflects the correlation between the structural response y and j-th structural parameter, and r_{sj} is positive, indicating that the structural response y increases with the structural parameter x_j and decreases with it; on the contrary, it is the opposite. The $| r_{sj} |$ reflects the degree of correlation between structural response y and structural parameter x_j, and namely, sensitivity is signified herein. Higher $| r_{sj} |$ indicates more sensitive structural response y to the structural parameter x_j, and namely, the impact of changes in structural parameter x_j is more significant to structural response y; otherwise, it is on the contrary [3].

Modeling and analysis

Definition of harsh working conditions
The general joint conditions of the clutch pressure plate have been analyzed in numerous domestic and foreign literatures [4, 7], but there is few analysis on complex and harsh working conditions. Failures such as fracture of clutch pressure plate often occur in bad working conditions. In order to fully simulate the harsh working conditions, twice slipping friction work is set in this paper for continuous engagement and disengagement of the clutch for 30 times. Simulation analysis in this paper is carried out in the harsh conditions.

Establishment of finite element model
Geometrical model of pressure plate is constructed using SolidWorks software, and it is imported into ANSYS software for meshing, and the element size is set to 4mm. After meshing, the total number of the elements is 139,008, and the total number of nodes is 441,314. Finite element model of the pressure plate is shown in the figure 1.
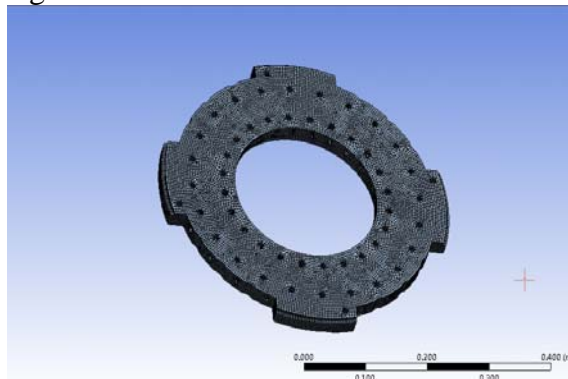

Fig. 1 Finite element model of the pressure plate

Impact of the thermal parameters on the clutch pressure plate performance
To explore the influence of the thermal parameters on the performance of the clutch pressure plate,

this paper conducts parameter setting from the ambient temperature, convective heat transfer coefficient on friction surface and convective heat transfer coefficient on non-friction surface, as the table 1 below.

Tab. 1 Thermal parameters of pressure plate and their range

thermal parameters	mean value	minimum value	maximum value
ambient temperature/ °C	110	90	130
convective heat transfer coefficient on friction surface/(W/m²·°C)	160	70	230
convective heat transfer coefficient on non-friction surface/(W/m²·°C)	140	70	230

Heat flux density on the surface of the pressure plate is calculated and applied as the boundary condition of the finite element model. Thermal-structure coupling analysis of the pressure plate is made using ANSYS to obtain the highest temperature and the maximum axial thermal deformation of the pressure plate under different thermal parameters, as shown in Figure 2.

No.	Ambient temperature of non-friction surface/°C	Convective heat transfer coefficient of non- friction surface/(W/m²·°C)	Ambient temperature of friction surface/°C	Convective heat transfer coefficient of friction surface/(W/m²·°C)	Maximum temperature of pressure plate/°C	Axial deformation of pressure plate/mm
1	110	150	110	150	356.18	0.18638
2	95.916	93.664	95.916	93.664	367.38	0.1931
3	124.08	93.664	95.916	93.664	374.36	0.19255
4	95.916	206.34	95.916	93.664	337.04	0.17658
5	124.08	206.34	95.916	93.664	349.74	0.18048
6	95.916	93.664	124.08	93.664	367.47	0.19315
7	124.08	93.664	124.08	93.664	374.45	0.19259
8	95.916	206.34	124.08	93.664	337.11	0.17664
9	124.08	206.34	124.08	93.664	349.81	0.18053
10	95.916	93.664	95.916	206.34	367.18	0.193
11	124.08	93.664	95.916	206.34	374.16	0.19245
12	90	150	110	150	348.9	0.18405
13	95.916	206.34	95.916	206.34	336.89	0.17647
14	124.08	206.34	95.916	206.34	349.59	0.18037
15	95.916	93.664	124.08	206.34	367.38	0.1931
16	124.08	93.664	124.08	206.34	374.36	0.19255
17	95.916	206.34	124.08	206.34	337.04	0.17659
18	124.08	206.34	124.08	206.34	349.74	0.18048
19	130	150	110	150	363.45	0.18643
20	110	70	110	150	377.56	0.19555
21	110	230	110	150	338.6	0.17516
22	110	150	90	150	356.09	0.18632
23	110	150	130	150	356.27	0.18644
24	110	150	110	70	356.27	0.18643
25	110	150	110	230	356.09	0.18632

Fig. 2 The highest temperature and the axial thermal deformation of the pressure plate under different thermal parameters

It can be obtained from the numerical analysis of the Figure 2 that under different thermal parameters, the maximum temperature of the pressure plate is 377.56 ℃, and the lowest temperature is 336.89 ℃. The range of the thermal parameters affecting the highest temperature of pressure plate is about 40 ℃, accounting for 10.8 percent. The maximum axial deformation of the pressure plate is 0.19555mm, and its minimum axial deformation is 0.17516mm; the range of the thermal parameters affecting axial thermal deformation is around 0.02mm, accounting for 10.4% of the maximum axial deformation.
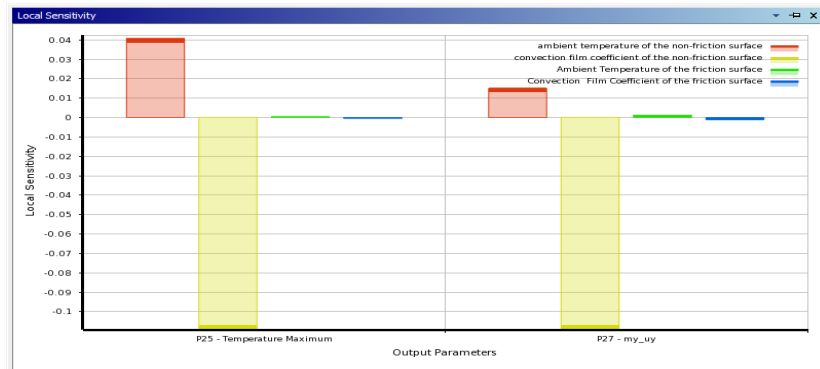

Fig. 3 Sensitivity of the thermal parameters to the highest temperature and the axial deformation of the clutch pressure plate

The figure 3 shows the sensitivity of the thermal parameters to the highest temperature and the axial deformation of the clutch pressure plate. Analysis from the figure 3 shows that the impact of ambient temperature on non-friction surface and convective heat transfer coefficient is greater, and especially the impact of convective heat transfer coefficient on non-friction surface is most obvious. The ambient temperature on non-friction surface is positively correlated to the highest temperature

and the axial deformation of the clutch pressure plate, and convective heat transfer coefficient on non-friction surface is negatively correlated to convective heat transfer coefficient of pressure plate. Namely, the higher the temperature of ambient temperature on non-friction surface is, the greater the highest temperature and the axial deformation of the pressure plate will be; the greater convective heat transfer coefficient on non-friction surface is, the smaller the highest temperature and the axial deformation of the pressure plate will be. There is basically no influence on ambient temperature and convective heat transfer coefficient on the friction surface. This is because the friction surface is the main heat source during the clutch engagement process, and it has short time in atmospheric convective heat transfer and small contact area. Non- friction surface always performs convective heat transfer during engagement and disengagement process, which is in line with the basic theory of heat transfer theory [8].

Impact of structural parameters on the clutch pressure plate performance

To explore the influence of the structural parameters on the performance of the clutch pressure plate, this paper conducts parameter setting from the distance between radial cooling channel and friction surface, the width and height of the radial cooling channel, the diameter of axial cooling through-hole, as shown in Table 2.

Tab. 2 Structural parameters of pressure plate and their range

geometry parameters	mean value	minimum value	maximum value
distance between radial cooling channel and friction surface/mm	5	4	9
width of radial cooling channel/mm	4	4	20
height of radial cooling channel/mm	10	5	20
diameter of axial through-hole (close to inner ring)/mm	10	5	20
diameter of axial through-hole(close to outer ring)/mm	10	5	20

The 30 consecutive engagement and disengagement process is performed, and thermal-structure coupling analysis of clutch is made using ANSYS to obtain the maximum temperature and maximum axial thermal deformation of the different structural parameters, as shown in Figure 4.

No.	distance between radial cooling channel and friction surface/mm	width of radial cooling channel/mm	height of radial cooling channel/mm	diameter of axial through-hole (close to inner ring)/mm	diameter of axial through-hole(close to outer ring)/mm	maximum temperature of pressure plat/℃	axial deformation of pressure plate/mm	weight of pressure plate/kg
1	6.5	12	12.5	12.5	12.5	415.14	0.25567	23.627
2	6.5	12	12.5	12.5	5	416.18	0.29088	24.078
3	6.5	12	12.5	12.5	20	415.14	0.21573	22.774
4	5.7917	9.7333	10.375	10.375	14.625	402.48	0.21884	24.521
5	7.2083	9.7333	10.375	10.375	10.375	396.87	0.27915	24.916
6	5.7917	14.267	10.375	10.375	10.375	430.67	0.31537	23.929
7	7.2083	14.267	10.375	10.375	14.625	420.05	0.33457	23.552
8	5.7917	9.7333	14.625	10.375	10.375	407.97	0.18231	24.204
9	7.2083	9.7333	14.625	10.375	14.625	402.24	0.23815	23.87
10	5.7917	14.267	14.625	10.375	14.625	438.58	0.25572	22.491
11	7.2083	14.267	14.625	10.375	10.375	431.24	0.35911	22.870
12	4	12	12.5	12.5	12.5	432.47	0.11558	23.596
13	5.7917	9.7333	10.375	14.625	10.375	403.21	0.21005	24.488
14	7.2083	9.7333	10.375	14.625	14.625	398.51	0.22412	24.108
15	5.7917	14.267	10.375	14.625	14.625	431.2	0.24882	23.121
16	7.2083	14.267	10.375	14.625	10.375	419.96	0.33086	23.519
17	5.7917	9.7333	14.625	14.625	14.625	406.92	0.14201	23.469
18	7.2083	9.7333	14.625	14.625	10.375	405.23	0.22673	23.839
19	5.7917	14.267	14.625	14.625	10.375	438.72	0.2542	22.461
20	7.2083	14.267	14.625	14.625	14.625	428.67	0.28868	22.135
21	9	12	12.5	12.5	12.5	403.65	0.31943	23.666
22	6.5	4	12.5	12.5	12.5	377.93	0.18538	25.508
23	6.5	20	12.5	12.5	12.5	476.09	0.50572	21.526
24	6.5	12	5	12.5	12.5	399.02	0.29120	25.208
25	6.5	12	20	12.5	12.5	431	0.25331	22.208
26	6.5	12	12.5	5	12.5	415.45	0.31155	24.113
27	6.5	12	12.5	20	12.5	415.16	0.18198	22.696

Fig. 4 The highest temperature and maximum axial thermal deformation of pressure plate under different structural parameters

It can be obtained from the Figure 4 that under different structural parameters, the maximum temperature of the pressure plate is 476.09℃, and the lowest temperature is 377.93℃. The range of the thermal parameters affecting the highest temperature of pressure plate is about 98℃, accounting for 20.6％; the maximum axial deformation of pressure plate is 0.50572mm, and its minimum axial deformation is 0.11558mm; the range of the thermal parameters affecting axial thermal deformation is about 0.39mm, accounting for 77.1％ of the maximum axial deformation. The maximum mass of pressure plate is 25.508kg, while the minimum mass is 21.526kg; the range of structural parameters affecting the mass of pressure plate is about 4kg, accounting for 15.6 ％ of the largest value.
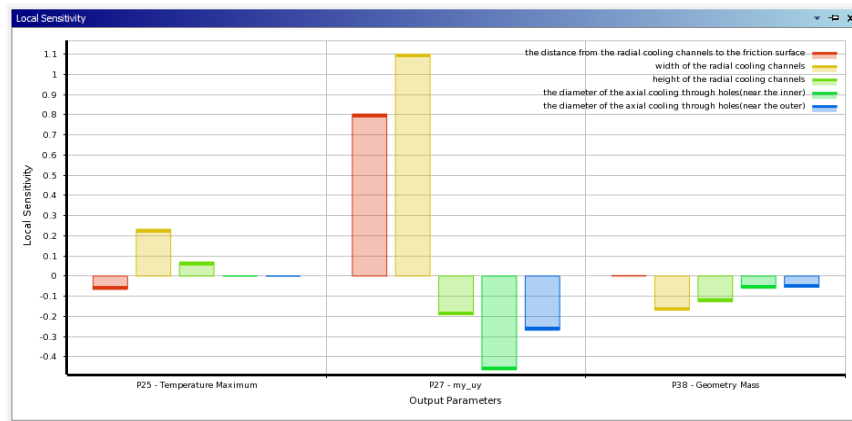
Fig. 5 Sensitivity of structural parameters to the highest temperature and the axial deformation of the clutch pressure plate

The figure 5 shows the sensitivity of the structural parameters to the highest temperature and the maximum axial deformation of the clutch pressure plate. The highest temperature: it is negatively correlated to the distance between the radial cooling channel to the friction surface, while positively correlated to the width and height of radial cooling channel. The distance between the radial cooling channel to friction surface, and width and height of radial cooling channel are highly influenced. In particular, the impact of the width of the radial cooling channel is the greatest. There is basically no influence of the axial through -hole. The distance between the radial cooling channel to the friction surface and the width of radial cooling channel are positively correlated and greatly affected. The height of radial cooling channel and axial through-hole diameter are negatively correlated. Pressure plate weight: there is basically no influence on the distance between the radial cooling channel to the friction surface. The width and height of the radial cooling channel and axial through-hole diameter are negatively correlated and slightly affected.

To reduce the maximum temperature and the axial deformation of the pressure plate and to reduce the mass of the pressure plate, the optimized structural parameters and results of the pressure plate are obtained and validated. As shown in the figure 6, it is proven that the results of the optimized pressure plate based on the response surface optimization and the actually verified results based on the FEM simulation: the maximum temperature error is 1.2%, the error of pressure plate weight is 1.1%, and the error of axial deformation is 5.5%, which complies with the basic requirements of optimum structural design.

Candidate Points		Candidate Point 1	Candidate Point 1 (verified)
P46 - DS_H1@	2@430L30_kong(541010).Part	5.3625	
P47 - DS_w1@	12@430L30_kong(541010).Part	4.5393	
P48 - DS_H2@ .Part	4@430L30_kong(541010)	15.213	
P49 - DS_D4@	14@430L30_kong(541010).Part	13.456	
P50 - DS_D3@	14@430L30_kong(541010).Part	19.002	
P25 - Temperature Maximum (C)		★ 376.6	✕ 381.35
P38 - Geometry Mass (kg)		✕ 24.542	✕ 24.276
P45 - my_uy2		★ 0.067436	★ 0.071368

Fig. 6 Optimized structural parameters and results verification

To facilitate manufacturing process available, the approximate values of the optimized structural parameters are taken, which is namely that the distance between radial cooling channel to friction surface is 5.4mm; the width of the radial cooling channel is 4.5mm; the height of the radial cooling channel is 15.2mm; the axial through-hole diameter (near inner side) is 13.5mm, and axial through -hole diameter (closer to the outer side) is 19.0mm. Compared with the original pressure plate, the maximum temperature of the optimized pressure plate remains constant. The new optimized pressure plate has reduced weight of 3.5kg, which is conducive to lightweight clutch and reduces production costs. The axial deformation amount of the new pressure plate is decreased from original 0.29mm to 0.07mm, and the axial deformation is significantly reduced. The working life and the reliability of the optimized pressure plate have been improved significantly.

Conclusions

(1) Within the considered parameters scope, the impact of the thermal parameters on the maximum temperature and the axial deformation of the clutch pressure plate is not obvious, and the fluctuation range is about 10%, of which the impact on convective heat transfer coefficient of non-friction surface is the greatest, and there is basically no influence on ambient temperature of friction surface and convective heat transfer coefficient.

(2) Within the size range considered, the impact of the structural parameters on the highest temperature and axial deformation of the clutch pressure plate is greater, of which range of the highest temperature variation has reached 20.6%; range of axial deformation variation has reached 77.1%. The maximum impact factor for maximum temperature of pressure plate is width of radial cooling channels and they are positively correlated. The maximum impact factor for the axial deformation of the pressure plate is the distance between the radial cooling channel and the friction surface as well as width of radial cooling channel and they are positively correlated respectively.

(3) The maximum temperature of the clutch pressure plate after size optimization is 380.79℃, and the axial deformation is reduced from 0.29mm to 0.07mm, and there is weight loss of 3.5Kg. Working performance of the optimized pressure plate has been improved significantly.

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