Internal Flowpath Optimization of Wet Multi-plate Friction Clutch

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Abstract. The research about internal flowpath optimization of wet friction clutch has significant effect on the reduce of heat generating. Taking the diameter and position of nozzle as design parameters, the maximum and minimum lubricant pressure as constraint conditions, and the RMS of lubricant pressure applied on friction disc and dual plate as objective function, the parametric FEM optimum model of flowpath about clutch is established. Based on the method of second order response surface, the paper sets up the response surface function of objective function by structure parameter, and optimizes the objective function through quadratic programming. The optimized structure of flowpath is obtained, and the rationality of optimization result is verified.

Introduction

Wet friction clutches in large marine gearbox are assembled in pair, when one is engaged, the other is in disengaged operation. Ideally, the clearances between friction discs are filled with lubricant under the disengaged operation, and heat will not be generated too much. When the structure of flowpath is designed unreasonably, the lubricant pressure between friction discs will distribute unevenly. As a consequence, thicknesses of clearance become inconsistent, which then leads the lubricant temperature to increase greatly so that clutches can not work normally.

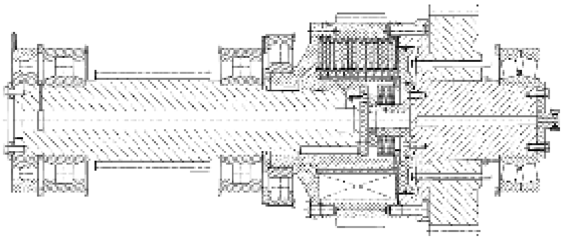
At present, domestic and foreign scholars have done a great deal of researches about the fluid field optimization of pipeline, valve, etc. Sargolzaei studied the neutral network algorithm, and optimized the fluid field of blade pattern about wind turbine [1]. Barcelos and Wang adopted quadratic programming to implement the structure optimization of airfoil and inner fluid channel about valve [2,3]. Derakhshan and Park employed different genetic algorithms to optimize the blade pattern of wind turbine and the airfoil [4,5].

The above works have important reference values. However, their study objects are mainly compressor blade, valve inner channel, and so on. And researches about structure optimization of clutch fluid field are still very few. Focusing on the complicated flowpath of wet friction clutch, the optimum research about fluid field of flowpath is carried out through treating uniformity of film pressure as objective, via which distributing film evenly to reduce the heat generated by clutch will be achieved.

Fluid Simulation of Wet Friction Clutch

Finite Element Model of Internal Flowpath. The structure of clutch is shown in Fig. 1, where there are 10 friction plates, 11 mating plates, and 3 groups of nozzles distributed in a circle with the position of 90°, 210° and 330°, and each group contains 10 nozzles. When the clutch is in disengaged operation, the 21 plates are separated equally by lubricant spraying from the nozzles.

The finite element model of the internal flowpath is established with ANSYS/CFD, as shown in Fig. 2. The research conducted is based on the assumption that the wall of oil is smooth and steady and the fluid near wall is processed with wall function, when all friction plates and mating plates are disengaged. The lubricant used is the CD40 marine lubricant with a density of 880 kg/m3, specific heat of 1600 J/(kg·ºC), and conduction coefficient of 0.144 W/(m·ºC).



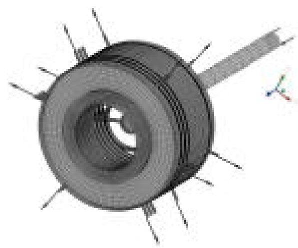


Fig. 1. Wet multi-disk friction clutch　　Fig. 2. Finite element mesh of flowpath

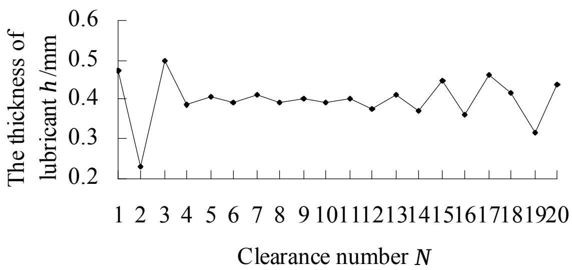
Numerical Calculation. The semi-implicit method for pressure linked equations (SIMPLEN) is used to solve the turbulence model, and the appropriate adjustment of relax coefficient provides quick convergence of the model. After iteration a convergent result can be got. Fig. 3. is the distribution curve of lubricant thickness in each clearance. The maximum thickness which locates in gap3 is 0.498mm, and the minimum thickness which locates in gap2 is 0.238mm.

Clutch Mathematical Model of Flowpath Optimization

Design Variables. Design parameters are variables which are changeable in the search process of optimum design. Once design parameters change, target response as objective function of fluid field optimization also will change. Because translation of friction disc is not taken into consideration in static analysis, lubricant pressure distributes unevenly and it will affect the status of film distribution and thermal power for actual operation of clutch. So diameter and position of nozzle which have important affect on lubricant pressure are chosen to be design parameters, as shown in Fig. 4. Determine parametric ranges according to the structure, as shown in Table 1. The specific expressions for design variables is Eq. 1.

$$X = X(d, x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8) \quad (1)$$

where d and x_i are the diameter and position of nozzle, $i = 1, 2 \ldots 8$ 。



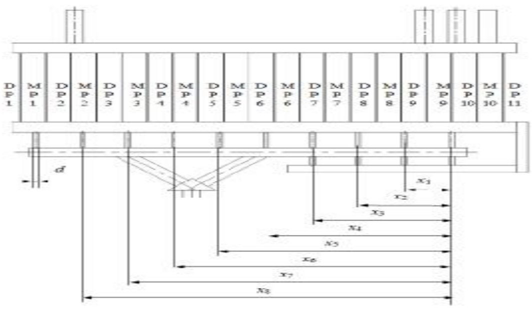


Fig. 3. The lubricant thickness　　Fig. 4 The schematic diagram of flowpath

Table 1. Initial value and range of design variables

Design variables	d	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
Initial / mm	3	27	53.5	79.5	106	132.5	158.5	185	211
Min / mm	2.5	26.5	53	79	105.5	132	158	184.5	210.5
Max / mm	3.5	27.5	54	80	106.5	133	159	185.5	211.5

Objective Function. Because discs are assumed to be distributed evenly in static optimum model, the status of clutch plate can only be reflected by resultant force. When the resultant force applied on each disc is small, the status is preferable, and lubricant temperature is lower. So the minimum value of the RMS of total lubricant pressure is taken as optimization objective and the objective function is Eq. 2.

$$\min f(x) = \min\{1/19 * \text{sqrt}(F_{\mathbf{DP2}}^{2} + F_{\mathbf{DP3}}^{2} + \cdots + F_{\mathbf{DP10}}^{2} + F_{\mathbf{MP1}}^{2} + F_{\mathbf{MP2}}^{2} + \cdots + F_{\mathbf{MP10}}^{2})\} \quad (2)$$

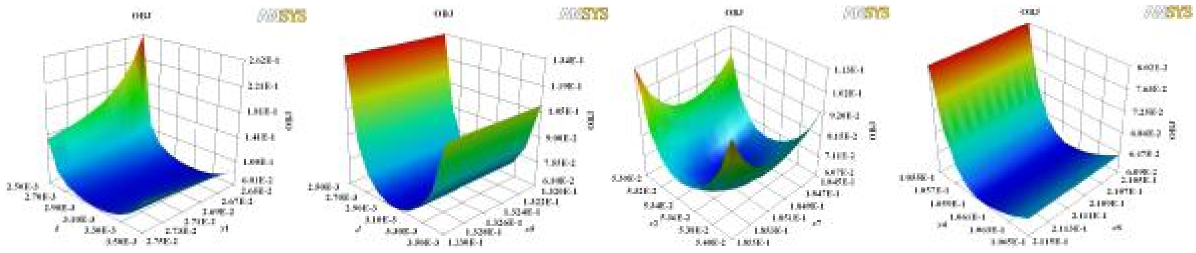
where $F_{\mathbf{DPi}}$ and $F_{\mathbf{MPj}}$ are the total lubricant pressure acting on DPi and MPj.

The Response Surface Model. Using the DesignXplorer module of ANSYS Workbench, some sample points are obtained by CCD method, and then CFD simulation is conducted. As is shown in Table 2, the sample points for establishing the response surface model are achieved.

Table 2. Part of the statistics of design points of the clutch by CCD method

Number	d	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	f
1	3.00	27.00	53.50	79.50	106.00	132.50	158.50	185.00	211.00	0.066943481
…	…	…	…	…	…	…	…	…	…	…
147	3.23	27.23	53.73	79.73	106.23	132.73	158.73	185.23	211.23	0.085735388

Based on sample points of the above table, regression analysis is carried out through least square method. After data fitting by programming, each coefficient of second order response function can be gotten, and then response surface model of flowpath optimization. Via test, the model can accurately simulate response of objective function to the structure parameter about flowpath optimization. Fig. 5 shows part of response surface of optimum target.



(a) d-x_1 (b) d-x_5 (c) x_2-x_7 (d) x_4-x_8

Fig. 5. Response charts of optimization object versus design variables

The Results of Optimization. Table 3 is the optimum design variables of the clutch after optimization.

Table 3. The optimum design variables of the clutch after optimization

Variable name	d	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
The initial value (mm)	3.00	27.00	53.50	79.50	106.00	132.50	158.50	185.00	211.00
The optimal value (mm)	2.97	26.96	53.45	79.37	106.20	132.22	158.66	185.22	210.73

Clutch Mathematical Model of Flowpath Optimization

According to the optimum design variables, the finite element model of internal flowpath is established again. Using finite element method, the flow field is analyzed, and then the distribution of the lubricant thickness is obtained, as shown in Fig. 6. Table 4 is the comparison of initial and final results of fluid optimization. The minimum thickness is 0.293mm, it increases by 23.11% than that (0.238mm), and the maximum thickness is 0.480mm, it decreases by 3.64% than that (0.498mm).

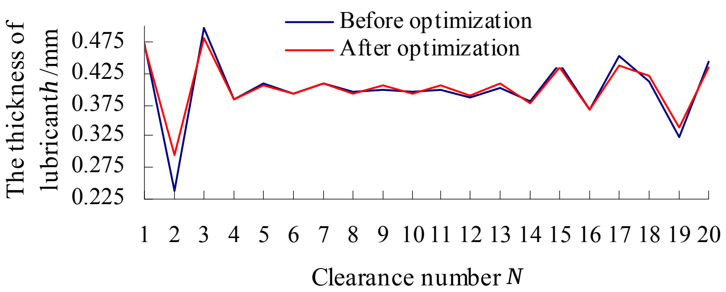


Fig. 6. The thickness of lubricant in each clearance

Fig. 7 is the lubricant pressure contour of the clutch after optimization. According to the figure, the maximum pressure is 183.999kPa, and it decreases slightly from 186.554kPa before optimization. Fig. 8 is the lubricant temperature contour after optimization. According to the figure, the maximum temperature is 97.041˚C, the maximum temperature difference is 39.041℃, and it decreases by 12.14% from 44.95˚C before optimization. Thus, the optimization effect is favorable.

Table 4. Comparison of initial and final results of fluid optimization

	Before optimization	After optimization	Optimization effect
h_{min} / mm	0.238	0.293	23.11%
h_{max} / mm	0.498	0.480	3.64%
Δh / mm	0.260	0.187	28%

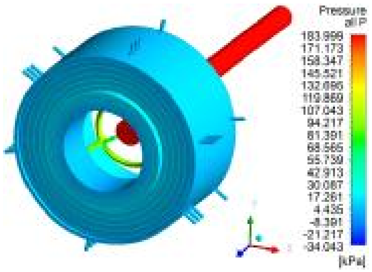


Fig 7. Pressure contour

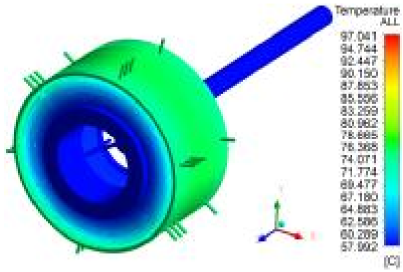


Fig 8. Temperature contour

Conclusions

1) Based on the fluid field analysis, taking the diameter and position of each nozzle as design parameters, the maximum and minimum lubricant pressure as constraint conditions, this paper establishes the parametric FEM optimum model about the flowpath while the minimum RMS of forces applied on each disc is the object.

2) Adopting response surface method, the second order response surface function of optimal object by structure parameter is obtained, and the optimized structure parameter about flowpath is solved through optimization calculation.

3) The maximum difference of clutch temperature is 39.041˚C after optimization, a decrease by 12.14% from 44.95˚C before optimization, which means the optimum effect is favorable.

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