



# RESEARCH ON THE EFFECTS OF DOUBLE ARC OIL GROOVE PARAMETERS ON TORQUE CHARACTERISTICS IN HYDRO-VISCOUS DRIVE

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**Abstract.** To analyze effect of double arc oil groove parameters on shear torque characteristics, a numerical simulation flow field model of hydro-viscous drive(HVD) in full oil film shear stage was built, and flow field characteristics of velocity distribution, pressure distribution and shear torque were obtained. The parameter analysis platform of oil grooves was integrated with the parameterized design of oil grooves(CAD), numerical simulation of flow field(CFX) and design of experimental(DOE). The effects of double arc oil groove parameters, including the width of groove, the number of grooves, the eccentricity of double arc oil grooves, the diameter of inner eccentric and the depth of oil groove on the shear torque of oil film in HVD were analyzed by using orthogonal arrays. The relationship between the oil groove parameters and shear torque of oil film were analyzed.

**Keywords:** Hydro-viscous drive(HVD), Double arc oil groove, Shear torque of oil film, Effect of oil groove parameters.

## 1. INTRODUCTION

HVD utilizes oil film to transmit power, and it is commonly used in mechanical equipment like fans, pumps, belt conveyors and scraper conveyors. It is the third fluid power transmission technique after hydraulic and hydrodynamic transmission. The double arc oil grooves are widely used in engineering industry, and the friction pairs constituting of friction plate(FP) and separator disk(SD) is key component. Therefore, accurate analysis of flow field characteristics and oil groove parameters is key step to predict torque characteristics and design oil groove parameters.

Most researches about the relation between shear torque and grooves focused on the wet clutch<sup>[1-3]</sup>, although the HVD has some similarity with wet clutch, more researches need to be done. Summarizing the previous work, the influence of effective area ratio on the shear torque was well studied. However, the present studies about grooves mostly concentrate on circumferential grooves<sup>[2]</sup>, radial grooves<sup>[3,4]</sup> and the inclined radial grooves<sup>[5-7]</sup>. However, the double arc grooves are more common in the engineering. So the effect of the double arc grooves needs to be studied further.

## 2. PARAMETERIZED ANALYZING PLATFORM

The previous researches about the influence of the double arc grooves parameters on the output torque are not sufficient, because the simulations about groove parameters are ponderous and repetitious. Therefore, an iSIGHT platform utilizing the multidisciplinary optimization was built to analyze the influences of groove parameters including the width  $d$ , the number  $n$ , the eccentricity  $l$ , the inner diameter of eccentric  $d_0$  and the depth of oil groove  $h_g$  on the torque characteristics. The platform integrated CAD and CAE by geometric module and finite module. And the effects of parameters on the output torque of HVD were analyzed in the parameter analyzing module. By utilizing the trail files, the script files, the batch commands and the parameterized command stream, the simulations were automatically driven. The platform is shown as Fig. 1.

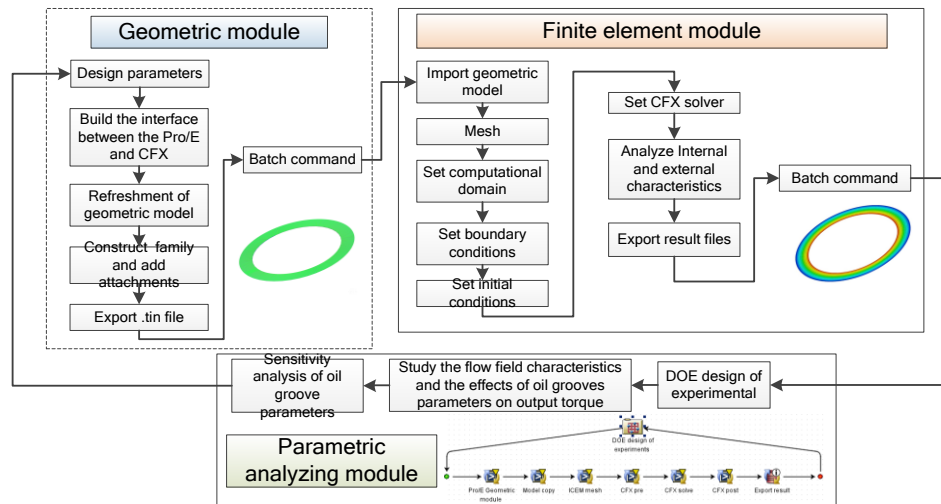


FIG 1. iSIGHT parameters analyzing platform

The trail files were used in the parametric modeling, and it reliably guaranteed the transition of oil groove parameters. Parametric modeling of geometric model is completed by Pro/E trail file, and the seamless connection between Pro/E and ANSYS is achieved by interface module. When the geometric parameters were altered, the family and its attachment were unchanged. By refreshing the geometric model, the new one was saved and exported as “.tin files”.

Computational domain, boundary conditions and initial conditions were set, then the parallel computing was running by calling the ANSYS solver, after the results were analyzed, the result files were exported.

The effects of double arc oil groove parameters on the output torque of HVD were studied. The oil groove parameters analysis platform was built by iSIGHT software, integrating oil groove parameterized design, flow field numerical simulation, design of experiment.

### 3. SIMULATION AND RESULTS

The oil film between the FP and SD was analyzed, and a schematic diagram of oil film is shown as FIG 2. One period of the film disk is calculated, since the film is N-fold periods. And the corresponding parameters are shown as Table.1.

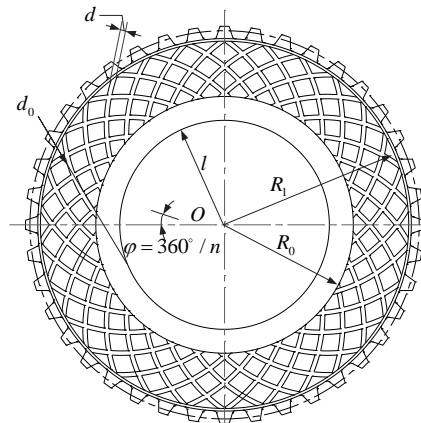


FIG 2. Schematic sketch of oil film

Table.1 The test conditions and geometric parameters for output torque test cases

Items	Parameters	Items	Parameters
inner radius of the FP $R_0$ /mm	512	density of oil $\rho$ [ $\text{Kg}\cdot\text{m}^{-3}$ ]	886
outer radius of the FP $R_1$ /mm	664	specific heat capacity of oil $c$ [ $\text{JKg}^{-1}\text{K}^{-1}$ ]	2093.5
thickness of oil film in the non-grooved area $h_r$ /mm	0.3	dynamic viscous of oil $\eta$ (Pa·s)	0.1848
thickness of oil film in the grooved area $h_g$ /mm	-	input flow rate of HVD $q$ ( $\text{L}\cdot\text{min}^{-1}$ )	0.0013376

inner diameter of grooves $d_0/\text{mm}$	-	temperature of oil $t/^\circ\text{C}$	40
width of grooves $d_0/\text{mm}$	-	rotational speed of SD $\omega_1/(\text{rev}\cdot\text{min}^{-1})$	54
the number of oil grooves $n$	-	rotational speed of FP $\omega_2/(\text{rev}\cdot\text{min}^{-1})$	0
eccentricity $l/\text{mm}$	-	The angle of one period of the oil film disk $\phi/(\text{ }^\circ)$	1

### 3.1 The effects of oil groove parameters on shear torque

The rotational speed of SD is constant and relatively small. The input flow rate is constant and more than the flow rate when the aeration occurs in different simulations. Therefore the aeration doesn't happen, and the friction pairs work in the full oil film stage. The effective area ratio changes with variation of the double arc groove parameters including the width of oil grooves  $d$ , the number of oil grooves  $n$ , the eccentricity  $l$ , the inner diameter of eccentric  $d_0$  and the depth of oil grooves  $h_g$ .

#### 3.1.1 Number of oil grooves

When the width of oil groove is 1.38mm, the eccentricity is 388mm, and the inner diameter of eccentric is 809mm and the depth of oil groove is 0.5mm. The relation between the shear torque of oil film and the number of oil grooves and the relation between the effective area ratio and the number of oil grooves are shown as FIG 3. The figure shows the increase of the number of oil groove causes the decrease of the effective area ratio. With the increase of the number of oil grooves, the shear torque of oil film shear torque declines. The trend of the effective area ratio, shear torque of oil film are same, when the width of oil groove varies.

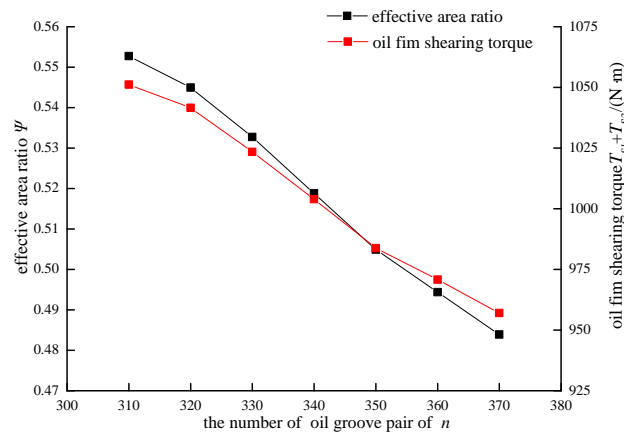


FIG 3. Relation between effective area ratio, shear torque and the number of oil grooves

#### 3.1.2 Width of oil groove

When the number of oil groove is 360, the eccentricity is 388mm, and the inner diameter of eccentric is 809mm and the depth of oil groove is 0.5mm. The relation between the shear torque of oil film and the width of oil groove and the relation between the effective area ratio and the width of oil groove are shown as FIG 4.

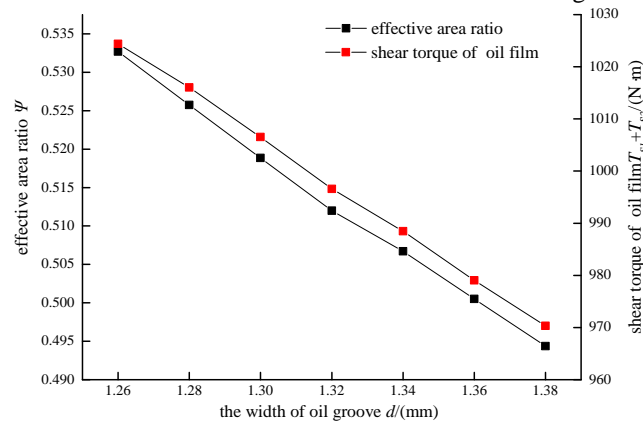


FIG 4. Relation between effective area ratio, shear torque and the width of oil groove

The figure shows the increase of the width of oil groove causes the decrease of the effective area ratio. With the increase of the width of oil groove, the shear torque of oil film shear torque declines. The trend of the effective area ratio, shear torque of oil film are same, when the width of oil grooves varies.

### 3.1.3 Eccentricity

When the number of oil grooves is 360, the width of oil groove is 1.38mm, and the inner diameter of eccentric is 809mm and the depth of oil groove is 0.5mm. The relation between the shear torque of oil film and the width of oil groove and the relation between the effective area ratio and the eccentricity are shown as FIG 5. When the eccentricity increases from 385mm to 391mm, the effective area ratio increases with the eccentricity, whereas the shear torque of oil film decreases gradually. This phenomenon happens since the eccentricity has great effect on not only on the effective area ratio but also on the velocity distribution. When the eccentricity increase from 391mm to 403mm, the effective area ratio curve and shear torque of oil film curve are both increase first then decrease. It is because of complex effects of eccentricity on the effective area ratio. The eccentricity too large or too small both can cause the arrangement of grooves near the inner diameter of FP too narrow, even there will be no grooves any more. Therefore, the certain value of the eccentricity exists, and let the effective area ratio be maximum. The trend of the effective area ratio, shear torque of oil film are almost same, when the eccentricity varies.

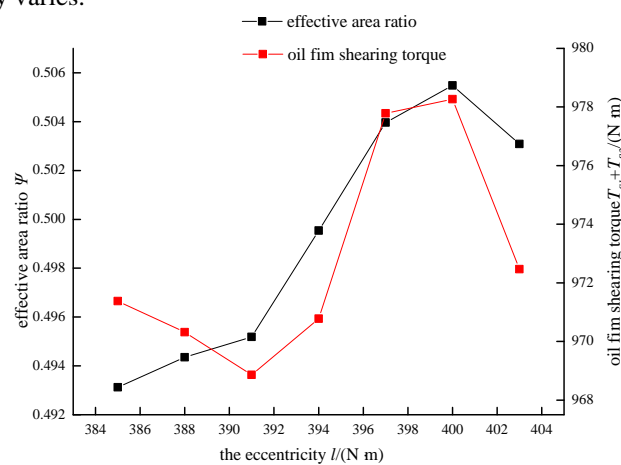


FIG 5. Relation between effective area ratio, shear torque and the eccentricity

### 3.1.4 Inner diameter of eccentric

When the number of oil grooves is 360, the width of oil groove is 1.38mm, and the eccentricity is 388mm, and the depth of oil groove is 0.5mm. The relation between the shear torque of oil film and the inner diameter of oil grooves and the relation between the effective area ratio and the inner diameter of grooves are shown as FIG 6. The figure shows the increase of the inner diameter of oil grooves causes the decrease of the effective area ratio. With the increase of the inner diameter of oil groove, the shear torque of oil film declines. The trend of the effective area ratio, shear torque of oil film are same, when he inner diameter of oil grooves varies.

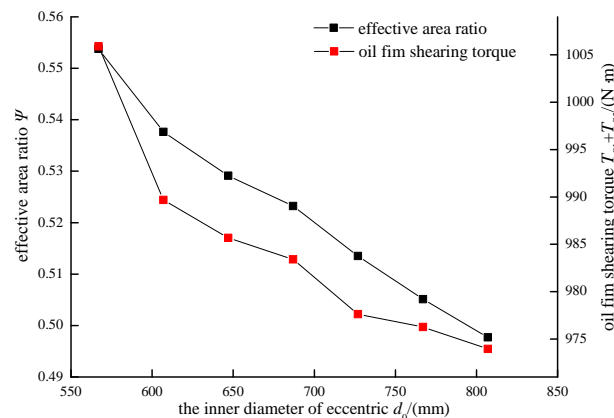


FIG 6. Relation between effective area ratio, shear torque and the inner diameter of eccentric

### 3.1.5 Depth of oil groove

When the number of oil grooves is 360, the width of oil groove is 1.38mm, and the eccentricity is 388mm, and the inner diameter of eccentric is 809mm. The relation between the shear torque of oil film and oil groove depth and the relation between the effective area ratio and oil groove depth are shown as FIG 7. The figure shows during the increase of oil groove depth, the effective area ratio keeps constant. While the depth of oil grooves increasing, the shear torque of oil film grows first then declines. It is because when the effective area keeps constant, the oil groove depth is another direct reason causing the change of shear torque of oil film. When the depth is less than 0.57mm, the increasing of it causes the change of velocity distribution, and then the shear torque of oil film grows. When the oil groove depth grows from 0.57mm to 0.63mm, the effect of oil groove depth on the shearing torque causing by bottom surface of the oil groove is more significant than the velocity distribution, so the shearing torque decreases.

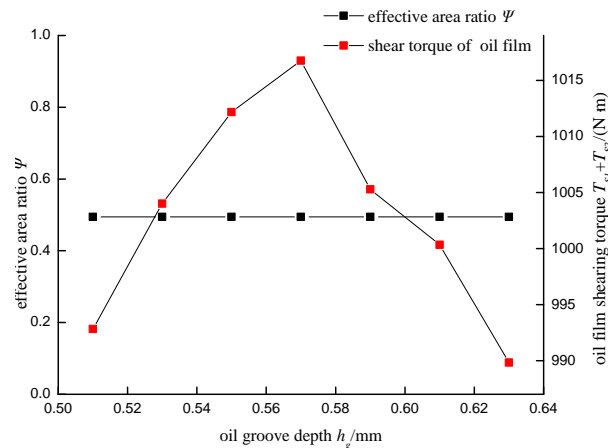


FIG 7. Relation between effective area ratio, shear torque and depth of oil groove

### 3.2 The effects of oil groove parameters on shocking torque

When the FP keeps stationary and the SD rotates at the angular speed  $\omega$ , the speed stream lines between the FP and SD are shown as FIG 8 and FIG 9. The figures show that the highest velocity of oil appears along the grooves whose direction is with the rotation direction of SD. Whereas oil moving along the grooves whose direction is against the rotation direction of SD gets its lowest value. The oil movement is different in the vertical direction. When  $0 < z < h_r$ , the oil is sheared by the drive of SD. The circumferential velocity is more than the radial velocity, the shear torque generated by oil film on the non-grooved area accounts for a large proportion in the output torque of HVD. When  $h_r \leq z \leq h_r + h_g$ , the oil moves along the grooves by the influence of the pressure difference between inner and the outer radius of the FP, the flow inertia and the centrifugal force. As a result, the radial velocity is more than the circumferential velocity. And the significant pressure difference exists in conjunctional zones between the grooved area and the non-grooved area, since the FP is stationary and the oil stroke the sidewalls of grooves. The groove sidewalls are subjected to the force caused by the pressure difference, and the grooved area of FP is subjected to the quite smaller shear stress by the oil movement along the grooves. The torque is generated by the two different kinds of mechanism.

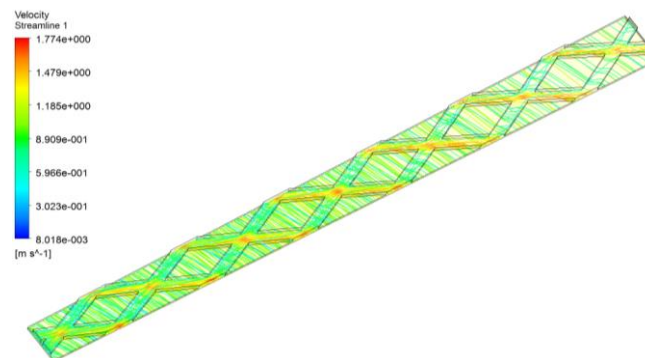


FIG 8. Stream lines of single period of oil film

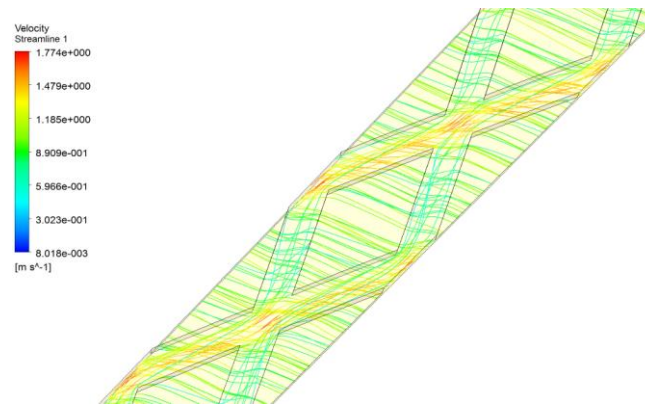


FIG 9. A partially enlarged view the stream lines of single period of oil film

### 3.2.1 Number of oil grooves

When the width of oil groove is 1.38mm, the eccentricity is 388mm, and the inner diameter of eccentric is 809mm and the depth of oil groove is 0.5mm. The relation between the shocking torque of oil film and the number of oil grooves is shown as in FIG 10. With the increase of the number of oil grooves, the shocking torque of oil film shear torque grows. When the input of oil is constant and the number of oil groove increase, so the effect of oil shocking on the sidewalls of oil grooves enhanced.

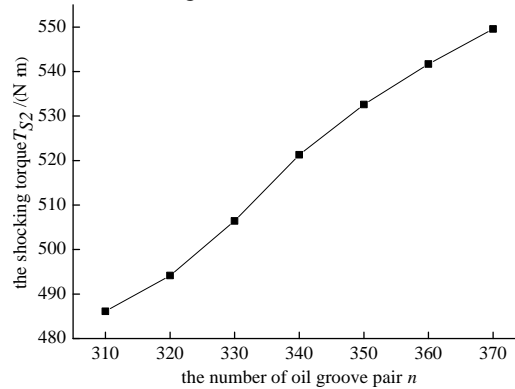


FIG 10. Relation between number of oil grooves and the shocking torque

### 3.2.2 Width of oil groove

When the number of oil groove is 360, the eccentricity is 388mm, and the inner diameter of eccentric is 809mm and the depth of oil groove is 0.5mm. The relation between the shocking torque and the width of oil groove is shown as FIG 11. The figure shows the shocking torque increases with the increase of the width of oil groove. It is because the velocity distribution changes with the oil grooves arrangement, and the effect of oil shocking enhances.

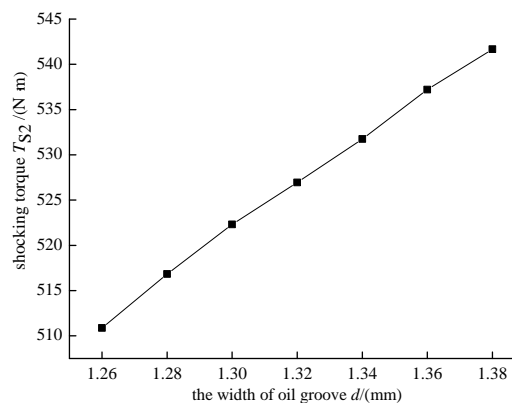


FIG 11. Relation between width of oil groove and the shocking torque

### 3.2.3 Eccentricity

When the number of oil groove is 360, the width of oil groove is 1.38mm, and the inner diameter of eccentric is 809mm and the depth of oil groove is 0.5mm. The relation between the shocking torque of oil film and the width of oil groove is shown as FIG 12. When the eccentricity increases, the shocking torque has an increase trend but gets fluctuations when the eccentricity is between 391mm to 401mm. It is because the eccentricity has complex effect on velocity distribution, therefore the shocking torque varies.

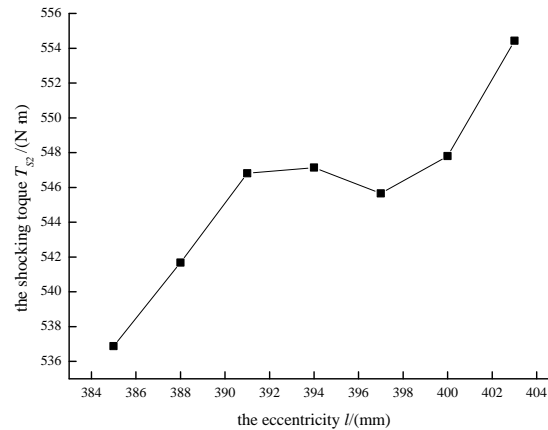


FIG 12. Relation between eccentricity and the shocking torque

### 3.2.4 Inner diameter of eccentric

When the number of oil grooves is 360, the width of oil groove is 1.38mm, and the eccentricity is 388mm, and the depth of oil groove is 0.5mm. The relation between the shocking torque of oil film and the inner diameter of oil grooves is shown as Fig 13. With the increase of the inner diameter of oil groove, the shear torque of oil film has a decreasing trend. With the variance of velocity distribution of the oil film, the shocking torque changes as the figure shows

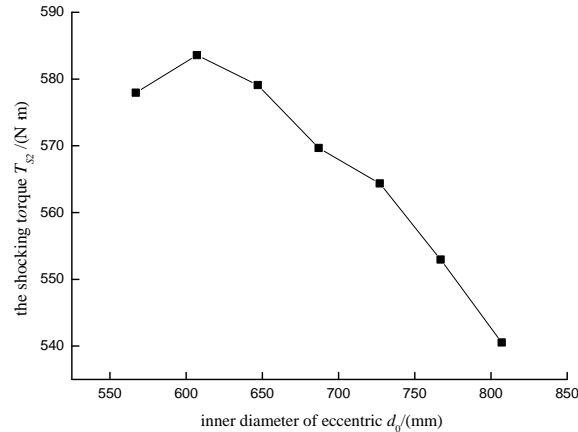


FIG 13. Relation between inner diameter of eccentric and the shocking torque

### 3.2.5 Depth of oil groove depth

When the number of oil grooves is 360, the width of oil groove is 1.38mm, and the eccentricity is 388mm and the inner diameter of eccentric is 809mm. The relation between the shocking torque of oil film and the oil groove depth is shown as FIG 14. With the increase of the oil groove depth, the shocking torque of oil film decreased. The velocity distribution of the oil film has a significant effect on the shocking torque.

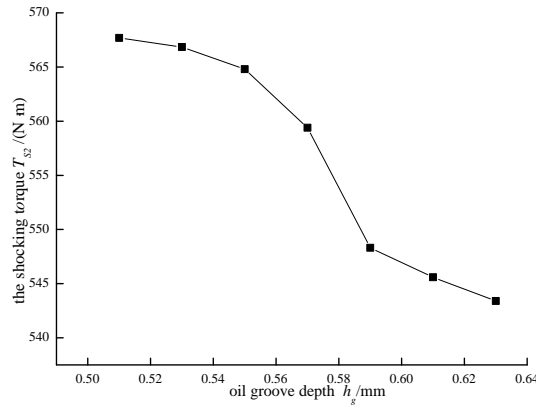


FIG 14. Relation between depth of oil groove and the shocking torque

### 3.3 The effects of oil groove parameters on output torque

The output torque of HVD in the oil film shearing stage consists of the shear torque and the shocking torque. Affected by dynamic pressure of flow field on the sidewall of oil grooves, the shocking torque produced by side walls of oil grooves is accounts for nearly 1/3 of the output torque of HVD. And the shearing torque accounts for nearly 2/3. Influences of width of oil grooves, the number of oil grooves, the eccentricity, the inner diameter of eccentric and the depth of oil grooves on the output torque were analyzed.

The geometric module and finite element module were packaged by simcode in iSIGHT. The effects of double arc oil groove parameters were analyzed by the design of equipment. The DOE was carried down by orthogonal arrays. The sensitivity of each parameter, main effects, and interaction effect were analyzed.

Pareto graph illustrates the effect of each oil groove parameter on the output torque. The blue bars represent the positive effects, they express that with the parameters grows, the response increases. While the red represent the negative effect, they express that with the parameters grows, the response decreases. As the FIG 15 shows, the positive response of the eccentricity, 14.37%, is most obvious than others. The interaction between the diameter of inner eccentric and eccentricity, accounting for 8.81%, has a quite strong positive effect on output torque. However, the interaction between the diameter of inner eccentric and the number of oil grooves has the most significantly negative effect, -12.69%.

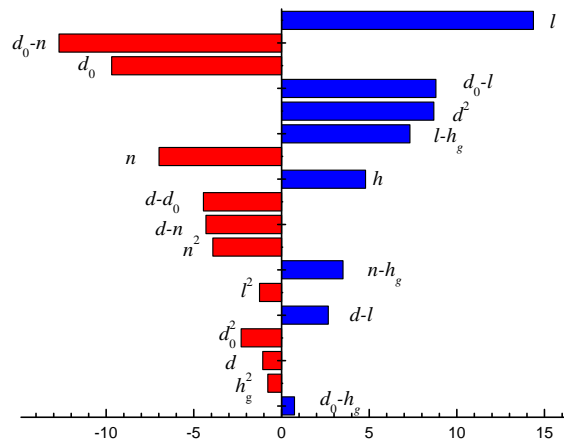


FIG 15. Pareto graph of the effects of oil groove parameters on output torque

In the FIG 16, the gradient of oil groove parameters is consistent with the effect in the pareto graph. The bigger the gradient is, the more obvious the effect of parameter on the response is. As figure shows, effect of the eccentricity and the depth are linear. With the effect of quadratic term, the effects of the diameter of inner eccentric, the number of oil grooves and the depth of oil groove on the output torque are parabolic.

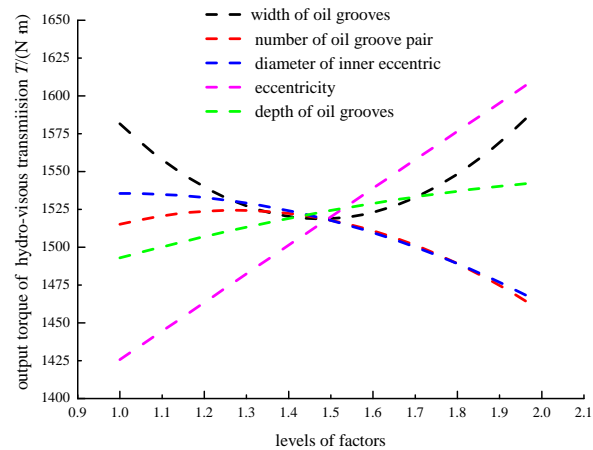


FIG 16. Main effect graph of effect of oil groove parameters on output torque

#### 4. CONCLUSIONS

The output torque consists of shear torque and the shocking torque. The shear torque of oil film increases with the width of oil grooves, the number of grooves and the diameter of the inner eccentric, and decreases with the growth of eccentricity. When oil groove depth grows, the shear torque gets fluctuated. The shocking torque increases with the width of oil grooves, the number of grooves and the eccentricity, and decreases with diameter of the inner eccentric and oil groove depth.

The eccentricity and diameter of the inner eccentric are sensitive parameters to the output torque.

The platform is integrated with CAD, CFX and DOE by utilizing trail files, script files, batch commands and parameterized command flow to set up parameters automatically and improve simulation efficiency. Effects of oil groove parameters on the shear torque are analyzed accurately, and a new method and theoretical foundation is provided for design of complex oil grooves of friction pairs of HVD.

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#### REFERENCES

1. FENG S.S., YAO S.W., LIU Q., Prediction on the fluid torque by shear stress in hydro-viscous drive with consideration of thermal effect. *Chinese Hydraulics & Pneumatics*, 2015, No.7, pp.89-92+95.
2. MIYAGAWA M, OGAWA M, O. Y., et al. Numerical simulation of temperature and torque curve of multidisk wet clutch with radial and circumferential grooves. *Tribology Online*, 2009, Vol.4, No.1, pp.17-21.
3. BERGER E. J., SADEGHI F., KROUSGRILL C. M., Finite element modeling of engagement of rough and grooved wet clutches. *Journal of Tribology*, 1996, Vol.118 No.1, pp.137-146.
4. XIE F. W., Influence Law of temperature field and deformed influence on hydro-viscous drive characteristics. Xuzhou: China University of mining and technology, 2010.
5. APHALE C. R., SCHULTZ W. W., CECCIO S. L., The influence of grooves on the fully wetted and aerated flow between open clutch plates. *Journal of Tribology*, 2010, Vol.132, No.1, 011104.
6. APHALE C. R., CHO J., SCHULTZ W. W., et al. Modeling and Parametric Study of Torque in Open Clutch Plates. *Journal of Tribology*, 2005, Vol.128, No.2, pp.422-430.
7. Razzaque M M, Kato T. Effects of groove orientation on hydrodynamic behavior of wet clutch coolant films. *Journal of Tribology*, 1999, Vol.121, No.1, pp.56-61.