FINAL SCRIPT: APPROVED FOR FILMING

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Title: Parametric Optimization Design Method for Friction Plates of Hydro-Viscous Clutches

Authors and Affiliations:
Xiangping Liao, Ying Zhao, Langxin Sun, Xinyang Zhu

School of Mechanical Engineering, Jiangsu University of Technology

Corresponding Authors:
Xiangping Liao lxp@jsut.edu.cn

Email Addresses for All Authors:
Ying Zhao zhaoying23x@163.com
Langxin Sun sunlangxin01@163.com
Xinyang Zhu zhuxy612@foxmail.com
Xiangping Liao lxp@jsut.edu.cn

Author Questionnaire

1. We have marked your project as author-provided footage, meaning you film the video yourself and provide JoVE with the footage to edit. JoVE will not send the videographer. Please confirm that this is correct.

√ Correct

2. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

3. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **Yes, all done**

4. Proposed filming date: To help JoVE process and publish your video in a timely manner, please indicate the proposed date that your group will film the **interviews** here: **MM/DD/YYYY**

When you are ready to submit your video files, please contact our China Location Producer, Yuan Yue.

Current Protocol Length

Number of Steps: 24
Number of Shots: 49 (48 SC)

Introduction

1.1. **Xiangping Liao:** This study focuses on designing friction plates for hydro-viscous clutches, aiming to achieve high torque transmission while reducing oil film temperatures.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 2.3.1*

What significant findings have you established in your field?

1.2. **Xiangping Liao:** Our study developed an optimization method combining Fluent analysis and response surface methodology for friction plate structure design.

1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 3.2.1*

What advantage does your protocol offer compared to other techniques?

1.3. **Xiangping Liao:** The method is applicable to friction plates of various sizes, offering versatility and efficiency.

1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 5.1.2*

Protocol

2. Simulation Analysis: Model Pre-Processing and Mesh Partitioning

Demonstrator: Ying Zhao

2.1. To begin, open the Workbench workstation **[1]** and drag the geometry from **Toolbox, Component Systems,** and **Geometry** into the project schematic area **[2]**. Right-click on the geometry, select **Import Geometry Model** to import the completed model, and click to edit the geometry model in Space Claim **[3]**.

2.1.1. WIDE: Talent taking a seat at the computer table. NOTE: Use 68328_R2(1).mp4 00:20-00:30

2.1.2. SCREEN: 68328_R2(5).mp4 00:00 – 00:10

2.1.3. SCREEN: 68328_R2(5).mp4 00:11 – 00:24

2.2. In the Space Claim toolbar, click on **Repair**, then select **Additional Edges** and **Split Edges** to complete the repair, merging the affected split lines **[1]**. Then, click on **Design** and **Selection in Selection**, select the inner surface of the model, and click **Create NS** in the group, naming it *Inlet* **[2]**.

2.2.1. SCREEN: 68328_R2(5).mp4 00:44 – 01:02

2.2.2. SCREEN: 68328_R2(5).mp4 01:08 – 01:26

2.3. Using the same process, click on the outer surface and name it *Outlet* **[1]**. Then, click on the smooth lower wall surface and name it *B* as the wall surface where the oil film contacts the passive friction pad **[2].** Select all unnamed surfaces and name them *Z* as the rotating wall surface where the oil film contacts the active friction pad **[3]**. Now, exit Space Claim and save the file to complete the pre-processing of the model **[4]**.

2.3.1. SCREEN: 68328_R2(5).mp4 01:27 -1:40

2.3.2. SCREEN: 68328_R2(5).mp4 01:40-01:50

2.3.3. SCREEN: 68328_R2(5).mp4 02:04-02:10

2.3.4. SCREEN: 68328_R2(5).mp4 02:11 – 02:18

2.4. In the Workbench workstation, drag **Fluent** from **Toolbox, Component Systems** and **Fluent** into the project schematic area where the geometry has been added **[1].** Click on **Geometry** and drag the mouse to the mesh in the Fluent project to link its Mesh

Module to the Upstream Data of the geometry **[2]**.

2.4.1. SCREEN: 68328_R2(5).mp4 02:19 – 02:28

2.4.2. SCREEN: 68328_R2(5).mp4 02:29 – 02:40

2.5. Double-click to open the mesh and select **Watertight Geometry** for mesh partitioning, then follow the workflow step-by-step **[1]** to import the geometry model and add **Local Sizing [2]**. Click **Generate Surface Mesh**, set the Minimum Size to 0.3 millimeters, the maximum size to 8 millimeters, and the Curvature Norm Angle to 10. After setting these parameters, click **Generate the Surface Mesh [3]**.

2.5.1. SCREEN: 68328_R2(5).mp4 03:26-03:33

2.5.2. SCREEN: 68328_R2(5).mp4 04:02-04:06

2.5.3. SCREEN: 68328_R2(5).mp4 04:07 – 04:32

2.6. Check the surface mesh quality by right-clicking on the generated surface mesh and selecting **Insert Improved Surface Mesh Quality**. Set the Minimum Mesh Quality to 0.7 and click **OK** to complete the improvement **[1]**. Click **Describe Geometry Model**, selecting the geometry model as consisting solely of a fluid region with no gaps, keeping other options at their defaults **[2]**.

2.6.1. SCREEN: 68328_R2(5).mp4 05:18 – 05:46

2.6.2. SCREEN: 68328_R2(5).mp4 05:48 – 06:00

2.7. Sequentially click **Describe Geometry Structure** and **Update Region Type Settings**, maintaining the default settings and completing the process **[7]**. Click **Add Boundary Layer**, selecting 3 for the number of layers, while keeping other settings at their defaults **[8]**.

2.7.1. SCREEN: 68328_R2(5).mp4 06:01 – 06:14

2.7.2. SCREEN: 68328_R2(5).mp4 06:18 – 06:28

2.8. Click **Generate Volume Mesh [1]** and insert an **Improved Volume Mesh** Quality to ensure its quality exceeds 0.12 **[2]**. After generating the mesh, click **Switch to Solution** and wait for the mesh partitioning and import to the analysis module to complete **[3]**.

2.8.1. SCREEN: 68328_R2(5).mp4 06:31 – 06:34

2.8.2. SCREEN: 68328_R2(5).mp4 13:10 – 13:20

2.8.3. SCREEN: 68328_R2(5).mp4 14:08 – 14:20

3. **Simulation Solving**

3.1. Switch from Mesh Partitioning to Solver Mode. Once the mesh has finished loading, click on **Check** in the **General** menu to validate the effectiveness of the finite element model and check whether the mesh has any negative volume **[1]**. Open the **Energy** Equation in the model settings, enter the viscous model settings interface, select the **Laminar** Model, and enable the **Viscous Heating** option **[2]**.

3.1.1. SCREEN: 68328_R2(5).mp4 14:50 – 15:04

3.1.2. SCREEN: 68328_R2(5).mp4 15:06 – 15:22

3.2. Modify the material parameters according to the properties of the two materials provided, adjusting the liquid material named *Air* **[1]** and the solid material named *Aluminum* **[2]**.

3.2.1. SCREEN: 68328_R2(5).mp4 15:26 – 15:36 and 15:52-15:53

3.2.2. SCREEN: 68328_R2(5).mp4 15:57-15:59 and 16:00-16:12

3.3. Click **Boundary Conditions**, select the active friction pad wall surface named *Z*, click on **Momentum Settings**, and set it as a rotating wall surface at 100 radians per second around the Y-axis with a shear condition of *No Slip* **[1]**.

3.3.1. SCREEN: 68328_R2(5).mp4 16:18 -16:25 and 16:35– 16:44

3.4. Click **Boundary Conditions**, select the passive friction pad wall surface named *B*, click on **Momentum Settings**, and set it as a stationary wall surface with a shear condition of *No Slip* **[1]**. Set the energy transfer-related boundary conditions **via System Coupling [2]**.

3.4.1. SCREEN: 68328_R2(5).mp4 16:46 – 16:56

3.4.2. SCREEN: 68328_R2(5).mp4 17:03 - 17:10

3.5. Next, set the outlet boundary conditions by selecting *Outlet*, setting it to **Pressure Outlet** with a gauge pressure of 0 **[1]**. Set the inlet boundary conditions by selecting *Inlet*, setting it to **Velocity Inlet** with a flow velocity of 1 meter per second and an inlet temperature of 30 degrees Celsius **[2]**.

3.5.1. SCREEN: 68328_R2(5).mp4 17:11 – 17:24

3.5.2. SCREEN: 68328_R2(5).mp4 17:25 – 17:45

3.6. Click on the **Solution** settings, select the **SIMPLEC** *(simp-lek)* algorithm for the solution method, choose the **First-Order Upwind** format for momentum and energy, and keep the residual values at default **[1]**. Set the state of the computational domain at the initial moment with an initial temperature of 26 degrees Celsius, pressure of 0 pascal, and zero velocity in the X, Y, and Z directions **[2]**.

3.6.1. SCREEN: 68328_R2(5).mp4 17:49 – 18:10

3.6.2. SCREEN: 68328_R2(5).mp4 18:11 – 18:30

3.7. Set the number of iterations to 300, click **Calculate**, and wait for the results **[1]**. Once the calculations are complete **[2]**, click **Results** followed by **Reports** and **Fluxes**, select **Mass Flow Rate** in Fluxes, and check inlet and outlet values to ensure the error is less than 0.1% **[3]**.

3.7.1. SCREEN: 68328_R2(5).mp4 18:32 – 18:44

3.7.2. SCREEN: 68328_R2(5).mp4 25:36-25:38

3.7.3. SCREEN: 68328_R2(5).mp4 25:46-26:02

3.8. Analyze the results by clicking **Results** followed by **Reports** and **Forces**, selecting torque around the Y-axis for wall surface *B*, and interpret the viscous value as the shear torque from the oil film **[1]**.

3.8.1. SCREEN: 68328_R2(5).mp4 26:06 – 26:30

3.9. Now, exit the fluid flow calculation module, drag **Results** from **Toolbox, Component Systems** and **Results** into the project schematic where the simulation is complete, then link the solution to the results module **[1]**. Enter the results, click on **Calculators**, select **Function Calculator** to solve for the average temperature of the oil film, and click **Calculate** to obtain the result **[2]**.

3.9.1. SCREEN: 68328_R2(5).mp4 27:20 – 27:30

3.9.2. SCREEN: 68328_R2(5).mp4 27:34 – 27:38 and 28:04 – 28:20

4. Parameter Optimization

4.1. In Design-Expert software, click on **NEW DESIGN** *(new design)* **[1]**. Under **Response Surface**, select **BOX-Behnken** *(box-ben-ken)* to establish a three-factor, two-level optimization model **[2]**.

4.1.1. SCREEN: 68328_R2(6).mp4 00:00 – 00:05

4.1.2. SCREEN: 68328_R2(6).mp4 00:06 – 00:14

4.2. Click on **Numeric Factors** to select three factors: the number of radial oil grooves in the friction pad, the depth of the grooves, and the arc length of the oil grooves, then fill in the corresponding table **[1]**. Enter the high and low-level values obtained from the analysis of the three influencing factors into the corresponding table **[2]**.

4.2.1. SCREEN: 68328_R2(6).mp4 00:14 – 00:26

4.2.2. SCREEN: 68328_R2(6).mp4 00:27 – 00:46

4.3. Set the **Center points per block** to 5, then click on the next step to change the **Response Variables** to 2, which are the torque transmitted by the oil film and the average temperature of the oil film. Click **Finish** to generate 17 sets of random sample points **[1]**.

4.3.1. SCREEN: 68328_R2(6).mp4 00:50 – 01:20 *Video editor: Please speed up*

4.4. Repeat the simulation analysis process to obtain the transmitted torque and average temperature of the oil film after recombination. Merge the predicted variables A, B, and C of the three influence combinations with the simulated results to form a new variable table **[1]**.

4.4.1. SCREEN: 68328_R2(6).mp4 01:52 – 02:02

4.5. Then, select **Quadratic** for the **Process Order** in the model, choose **Polynomial** for the **Model Type**, and keep other settings at default **[1]**. After establishing the response surface model, calculate both torque and average temperature **[2]**.

4.5.1. SCREEN: 68328_R2(6).mp4 02:10 – 02:20

4.5.2. SCREEN: 68328_R2(6).mp4 02:21 – 02:31

4.6. Conduct an error analysis of the model by clicking on **Analysis of Variance** and analyzing R^2 *(R-squared)* and Adeq Precision values in **Fit Statistics** to verify compliance with standards **[1]**.

4.6.1. SCREEN: 68328_R2(6).mp4 02:32 – 02:52

4.7. Click on **Optimization** followed by **Numerical** and **Criteria**, keeping the ranges for the three influencing factors unchanged, then click **Solutions** to find the maximum torque and minimum average temperature for the approximate values **[1]**. Calculate the results for different arrays, labeling combination 1 as the optimal solution for the model **[2]**.

4.7.1. SCREEN: 68328_R2(6).mp4 02:54 – 03:12

4.7.2. SCREEN: 68328_R2(6).mp4 03:13 – 03:20

Results

5. Results

5.1. The modeling and simulation process identified and optimized friction plate groove parameters that significantly influence oil film temperature and transmitted torque **[1]**. The transmitted torque decreases as the number of radial oil grooves increases. **[2]** but the average oil film temperature decreases accordingly. **[3]**.

5.1.1. LAB MEDIA: Figure 2.

5.1.2. LAB MEDIA: Figure 3. *Video editor: Highlight the plotted "torque" value on black line for groove count 20 on the X-axis*.

5.1.3. LAB MEDIA: Figure 3. *Video editor: Highlight the plotted "ave temp" value on red line for groove count 20 on the X-axis*.

5.2. Similarly, increasing the groove depth, arc length of radial grooves and number of circumferential oil grooves caused a similar reduction in transmitted torque **[1]** and a marked decrease in average oil film temperature to different extents **[2]**.

5.2.1. LAB MEDIA: Figure 4, 5, 6. *Video editor: Highlight the black "torque" points.*

5.2.2. LAB MEDIA: Figure 4,5,6. *Video editor: Highlight the red "ave temp" points*.

5.3. Three representative groove structures produced distinct oil film temperature distributions **[1]**, with notable differences in the outer ring's high-temperature zones **[2]**.

5.3.1. LAB MEDIA: Figure 7.

5.3.2. LAB MEDIA: Figure 7. *Video editor: highlight the red outer areas in A B and C*

5.4. The response surface model for average oil film temperature and torque showed a good alignment between predicted and actual values **[1]**.

5.4.1. LAB MEDIA: Figure 8.

5.5. The interaction of radial groove number and groove depth produced a sloped surface for torque response **[1]**, while the interaction of groove depth and arc length showed a steeper gradient **[2]**.

5.5.1. LAB MEDIA: Figure 9. *Video editor: Highlight A*.

5.5.2. LAB MEDIA: Figure 9. *Video editor: Highlight B*.

5.6. The interaction of radial groove number and groove depth created a gradual gradient in average oil film temperature **[1]**, while groove depth and arc length interaction yielded a sharper color transition **[2]**.

5.6.1. LAB MEDIA: Figure 10. *Video editor: Highlight A*.

5.6.2. LAB MEDIA: Figure 10. *Video editor: Highlight B*.

1. Workbench

- **Pronunciation link**: Cambridge Dictionary – shows US pronunciation /ˈwɝːk.bentʃ/ Ansys Learning Forum+77+دانلود سی پی7+دانلود سی پیYouTube+15Cambridge Dictionary+15Merriam-Webster+15
- **IPA**: /ˈwɝːk.bentʃ/
- **Phonetic Spelling**: *WURK-bench*

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2. Workbench model import (Focus on claim in "Space Claim")

- **Pronunciation link**: Cambridge Dictionary – *claim* pronounced /kleɪm/ YouGlishCambridge Dictionary+3Cambridge Dictionary+3Cambridge Dictionary+3
- **IPA**: /kleɪm/
- **Phonetic Spelling**: *klaym*

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3. Fluent (common in CFD software context)

- While I didn't find a direct source, pronunciation is standard:
- **IPA**: /ˈfluː.ənt/
- **Phonetic Spelling**: *FLOO-uhnt*

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4. Mesh

- Standard technical term with straightforward pronunciation:
- **IPA**: /mɛʃ/
- **Phonetic Spelling**: *mesh*

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5. Laminar (as in "Laminar Model")

- Common in fluid dynamics disciplines:
- **IPA**: /ˈlæm.ɪ.nɑɹ/
- **Phonetic Spelling**: *LAM-ih-nar*

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6. SIMPLEC (CFD solution algorithm)

- Treated as a technical acronym/name:
- **IPA**: /ˈsɪm.plɛk/
- **Phonetic Spelling**: *SIM-plek*

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7. Box–Behnken (Design-Expert response surface method)

- **Box** – /bɑːks/ – *bahks*
- **Behnken** – often pronounced /ˈbɛn.kən/ – *BEN-kən*

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8. Response Surface (modeling term)

- **Response** – /rɪˈspɑːns/ – *re-SPAHNS*
- **Surface** – /ˈsɝː.fɪs/ – *SUR-fiss*