NUMERICAL SIMULATION AS A TOOL FOR EV DEVELOPMENT

Multiphase SPH for powertrain applications
OUTLINE

1. Introduction to nanoFluidX & SPH
2. Oiling in an EV gearbox
   • Setup
   • Flow field analysis
   • Bearing supply and thermal analysis
3. Spray lubrication of an electric motor
   • Setup
   • Flow and thermal field analysis
4. Conclusions
5. Q & A
INTRODUCTION
ALTAIR AT A GLANCE

Founded 1985
Headquartered in Troy, MI US

71 office
in 24 countries

$396M
2018 Revenue

50+
ISV partners under our unique, patented licensing model

2000+
Engineers, scientists and creative thinkers

5000+
Customer installations globally

60,000+
Users
INTRODUCTION TO NANOFLUIDX

nanoFluidX is ...

- based on the Smoothed Particle Hydrodynamics method (SPH).
- a meshless CFD solver (Lagrangian).
- Navier-Stokes equations.
- most powerful for complex flows in arbitrary geometries.
- 100% GPU (Graphical Processing Unit) – therefore lightning fast.

Kuenen et al, 2015: http://dx.doi.org/10.1103/APS.DFD.2015.GFM.V0055#sthash.ZII8RphB.rHSVjkkl.dpuf
Although you see these particles as discrete, mathematically, they are a continuum (smooth).

- Every property of the owner particle can be expressed through the following volumetric integral:

\[
\tilde{A}(\mathbf{r}) = \int A(\mathbf{r}') W(\mathbf{r} - \mathbf{r}', h) d\mathbf{r}' \approx \sum_b A(\mathbf{r}_b) V_b W(\mathbf{r} - \mathbf{r}_b, h)
\]

Discretized form of the integral. Index \(b\) = number of the neighbour.

- We sum the influence of neighbouring particles.

Wall Boundary Condition
- We use particle layers at the wall to give “full support”.
- This gives proper physical results, independent of the geometry.
- It is numerically elegant, and easy to parallelise, therefore very fast.
WORKFLOW - SIMULATION
SIMULATION SETUP

- Gearbox of an electric vehicle
- Multiphase
- Physical time: 2 s
- Resolution: 0.75 mm
- No. of particles: 11.8M
- Pre-processing: 1 h
- 8x NVIDIA Tesla V100: 2d
TIME AVERAGING

• Creating pretty rendered videos is great, but gives little engineering insight.

• We look for a quasi steady state (unsteady convergence) condition, and time average the flow field over that window.

• We time average the flow field \rightarrow create a quasi-steady-state flow field.

• This provides more genuine flow insight answer the questions of how does the flow behave on average.
AVERAGE OIL DISTRIBUTION
There is a large low-velocity vortex structure above the middle shaft.
High velocity current coming from the output shaft breaks on the counter-rotating middle shaft and the flow gets split:

- One part recirculating the oil
- The other reaching the input shaft.
Recirculation zone formed below the middle shaft (supplied by oil coming from the input shaft)

Big gear on the middle shaft drives the oil back into the main sump.
CHURNING LOSSES

<table>
<thead>
<tr>
<th>Shaft</th>
<th>RPM</th>
<th>Torque [Nm]</th>
<th>Power [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2080</td>
<td>2.5</td>
<td>0.54</td>
</tr>
<tr>
<td>2</td>
<td>3170</td>
<td>0.43</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>6460</td>
<td>0.13</td>
<td>0.09</td>
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</tbody>
</table>

Total power loss: 0.73 kW
BEARING OIL SUPPLY and thermal results
Thermal situation is very critical in electric drivetrains.

- Oil flow affects temperature distribution.
- Timescales are very different between flow and thermal phenomena.

Solution – separate thermal and flowfield simulations.

- Transient fluid solver
- Time averaging and mapping of the flowfield
- Conjugate heat transfer simulation
HOUSING TEMPERATURES
BEARING OIL SUPPLY
Altair nanoFluidX™

E-Motor Cooling in Conjunction w/ AcuSolve
ELECTRIC MOTOR EXAMPLE

SIMULATION SETUP

Flow Simulation with nFX
- Multi-Phase Simulation
- Simulated time: \( t_{\text{sim}} = 1.5 \text{ s} \)
- Particle Size: \( d_x = 1 \text{ mm} \)
- Rotor speed: 4000 RPM
- Oil volume flow: \( \dot{V} = 7.53 \text{ l/min} \)
- 8x NVIDIA Tesla V100: 18 h

Thermal simulation
- Anisotropic material properties to represent coils and magnets
- Heat sources imported from Electromagnetic simulation.
- Water flow through radiator.
- Convective Heat Coefficient: 25 W/m2-K
RESULTS

Time: 1.180000

Oil Particles
RESULTS

Time Average Volume Fraction

Time Average Velocity Field
RESULTS
RESULTS

Thermal Field (AcuSolve)

- The lower half of the coils has the highest temperature in the system.
- There is a temperature difference between the front and back coils, with the back one being hotter.
- The temperature difference is likely caused by two mechanisms:
  
  - Difference in mass flow of the oil in front and back of the shaft (pressure drop in the shaft). → Less oil in the back → Higher temperatures
  - Also, the large cylindrical protrusion (see slide 4) on the front of the shaft causes higher velocities in the front of the motor → Better cooling.
CONCLUSIONS
CONCLUSIONS

• Transient nanoFluidX solution is time averaged to extract a quasi-steady-state flow field, providing engineering insight to the average flow behavior.

• Strong interaction between oil spray and air flow, especially vortex interaction in high RPM cases.

• Capturing this effect means that realistic thermal simulations can be carried out and temperature related effects studied.

• Being able to run these simulations in a short timescale with GPUs means that they can be part of an industrial design cycle.

• All simulations shown are the start of an engineering process, not the end.
THANK YOU FOR YOUR ATTENTION.