Vane oil pump analysis with GT-Suite

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Pierburg

European GT Conference
Steigenberger Airport Hotel Frankfurt
Frankfurt am Main, Germany
Outline

A variable displacement vane oil pump (VOP)

The GT-ISE model of a VOP:

1. inputs
2. development
3. outputs:
   3.1 speed sweep test results
   3.2 (transient) stability analysis results
   3.3 priming analysis results
Outline

- A variable displacement vane oil pump (VOP)
- The GT-ISE model of a VOP:
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  2. development
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A sliding VOP

- Housing
- Cover
- Pump outlet
- Pump inlet (suction pipe omitted)
A sliding VOP

Inlet volume of the pump

Rotor

Small ring

Pilot chamber of the pump

Vanes

Spring chamber of the pump

Control ring

Outlet volume of the pump
Sliding regulation mechanism

- Maximum eccentricity, maximum pump displacement

- Pump eccentricity reduces at increasing pump speed

- 1.5%-3.5% energy saving (fuel and CO$_2$) of a VD VOP with respect to a traditional pump
Hydraulic control system

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It will be shown during the presentation
1. Model inputs
GT-ISE model: input data

- Pump type (e.g. sliding or pivoting)
GT-ISE model: input data

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GT-ISE model: input data

- Pump type (e.g. sliding or pivoting)
- Preliminary dimensioning (Excel file)
GT-ISE model: input data

- Pump type (e.g. sliding or pivoting)
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- Preliminary CAD model
GT-ISE model: input data

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- Standard design tolerances (to estimate clearances)
GT-ISE model: input data

- Pump type (e.g. sliding or pivoting)
- Preliminary dimensioning (Excel file)
- Preliminary CAD model
- Standard design tolerances (to estimate clearances)
- Components features:
  - springs
  - seals
  - ball valves
  - control logic: valve type, assembly and (when available) model
GT-ISE model: input data from the engine manufacturer

- Engine basement CAD model: to measure pipes dimensions from pump outlet interface and to feedback pressure interface with pump
GT-ISE model: input data from the engine manufacturer

- Engine basement CAD model: to measure pipes dimensions from pump outlet interface and to feedback pressure interface with pump
- Engine pulley / sprocket to define transmission ratio
- Belt load and direction referred to engine CAD model
GT-ISE model: input data from the engine manufacturer

- Engine basement CAD model: to measure pipes dimensions from pump outlet interface and to feedback pressure interface with pump
- Engine pulley / sprocket to define transmission ratio
- Belt load and direction referred to engine CAD model
- Suction CAD and suction mesh Q/P curves
GT-ISE model: input data from the engine manufacturer

- Working conditions:
  - oil type
  - temperature $T[^\circ C]$ range
  - aeration level vs. engine speed and temperature

![Graph showing oil aeration at different engine speeds.](image-url)
GT-ISE model: input data from the engine manufacturer

- Working conditions:
  - oil type
  - temperature $T[^\circ C]$ range
  - aeration level vs. engine speed and temperature
- Engine speed $n[\text{RPM}]$ range
- Accepted feedback pressure range in regulation
GT-ISE model: input data from the engine manufacturer

- Working conditions:
  - oil type
  - temperature $T[°C]$ range
  - aeration level vs. engine speed and temperature

- Engine speed $n[RPM]$ range

- Accepted feedback pressure range in regulation

- Engine permeability curves: pump outlet flow rate/pressure curves and outlet-feedback pressure drop

6.4.1. Perméabilité moteur

6.4.1.1. A 155°C :

6.4.1.1.1. Moteur Neuf

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6.4.2. Perte de charge sortie pompe/Rampe principale

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</table>
GT-ISE model: input data from the engine manufacturer

- Working conditions:
  - oil type
  - temperature $T[^\circ C]$ range
  - aeration level vs. engine speed and temperature

- Engine speed $n[RPM]$ range

- Accepted feedback pressure range in regulation

- Engine permeability curves: pump outlet flow rate/pressure curves and outlet-feedback pressure drop

- Design point
2. Model development
Housing and cover porting plates
Port areas vs angle estimation

- **In-house developed** Matlab® (MathWorks) routine
- Cover/housing up/down and lateral ports (control ring slots)
- Accounting for:
  - actual eccentricity
  - porting plates angles and shape
  - begin delivery shape (standard, V-groove, slot)
Reference system
Geometry
Geometry
Geometry and volumes
Geometry and volumes
Shape to component conversion in GEM3D environment

Mesh shapes

Components
Shape to component conversion in GEM3D environment

Imported mesh shape → Port clipping and identification → Component

flowsplit → Pipe
GEM component to GT-ISE model conversion

Components

GEM vane pump template

Preliminary GT-ISE model
GT-ISE model

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GT-ISE model

Sliding pump
7 rotor chambers

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GT-ISE model

OMITTED FOR INTERNAL POLICIES

OMITTED FOR INTERNAL POLICIES

OMITTED FOR INTERNAL POLICIES

Suction pipe

Suction mesh not included
GT-ISE model

Inlet volume

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GT-I SE model

Outlet volumes

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OMITTED FOR INTERNAL POLICIES

OMITTED FOR INTERNAL POLICIES

European GT conference 2015 – VOP analysis
GT-ISE model

Pilot chamber
Spring chamber
GT-ISE model

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OMITTED FOR INTERNAL POLICIES

OMITTED FOR INTERNAL POLICIES

Control channels
Leakages:
- between rotor chambers
- towards rotor center
- from/to control chambers
Clearance estimation

- **In-house developed** Excel routines

- **Leakage type:**
  - axial rectangular gap
  - annular gap
  - chamfers

- **Depending on:**
  - tolerances
  - temperature
  - material

- **Classified as:**
  - Min
  - Mean
  - Max

Leakages:
- between rotor chambers
- towards rotor center
- from/to control chambers
GT-ISE model

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Bearings
GT-ISE model

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Hydraulic spool valve
ON-OFF Valve (equivalent orifice approach)

GT-ISE model

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GT-ISE aeration modeling

- Based on the Henry-Dalton law

\[ V_{\text{gas-d,ss}} = \frac{BV_{\text{liq}}}{1 \text{Bar}} \]

- First order dynamics of gas transition

\[ \frac{d(m_{\text{gas,dis}})}{dt} = \frac{(m_{\text{gas,dis,ss}} - m_{\text{gas,dis}})}{\tau^*} \]

- Max gas volume (free state @1 Bar, 273 K) dissolvable in the liquid at steady-state

- Liquid volume available to dissolve gas

- Pressure in the volume

- Bunsen coefficient

- Actual mass of dissolved gas

- Mass of dissolved gas at steady state

- \( \tau^* = \) time constant:

  - \( \tau_{fd} = \) free->dissolved (if \( m_{\text{gas,dis}} > m_{\text{gas,dis,ss}} \))
  - \( \tau_{df} = \) dissolved->free (if \( m_{\text{gas,dis}} < m_{\text{gas,dis,ss}} \))
GT-ISE fluid definition

- FluidGas
  - air2
  - oil-vap
- FluidInitialState
  - init
- FluidLiqAeration
  - oilarmixproperties
- FluidLiqAerationInit
  - oilarmix
- FluidLiqCompressible
  - Oil-5W30-62-10cSt

On-line aeration measurement

Table:

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<th>Object Value</th>
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<tr>
<td>Composition</td>
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<td>[fluid]</td>
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Table:

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<th>Object Value</th>
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Table:

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<th>Object Value</th>
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<tr>
<td>Maximum Valid Temperature</td>
<td>K</td>
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<tr>
<td>Minimum Valid Pressure</td>
<td>bar</td>
<td>1e-8</td>
</tr>
<tr>
<td>Maximum Valid Pressure</td>
<td>bar</td>
<td>1500</td>
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</table>
Model validation

- Through in-house experimental activities on test benches
- Real time free air content measurement with Air-X® (DSI)
- Compared outputs:
  - pressure
  - volumetric flow
  - adsorbed torque
Adsorbed torque estimation

- In-house developed relations and Matlab® (MathWorks) routine (by Politecnico of Turin)

Power loss for viscous friction:
- due to fluid shear stresses inside lubricated clearances in the pump
- function of rotational speed, viscosity and clearance size and shape
- historically, Wilson model has been used for preliminary evaluations

Power loss for Coulombian friction (dependent on delivery pressure and rotation speed):
- due to the contact between surfaces with relative motion
- function of rotational speed n (vanes centrifugal force)

Adsorbed torque estimation

\[ W_A = W_{CL} + W_\mu + W_T \]

Theoretical hydraulic power:
- due to real pressure present in pump chambers
3. Model outputs
3.1 Speed sweep test results
Results

**Delivery pressure**

- 7% aeration - OFF state
- 1% aeration - ON state

**Delivery flow rate**

**Main gallery pressure**

**Eccentricity**
Results

Pilot chamber pressure

Internal pump force along eccentricity

Spring chamber pressure

7% aeration - OFF state
1% aeration - ON state
Results

- Hydraulic spool valve position

OFF hole discharged flow rate:
- 7% aeration - OFF state
- 1% aeration - ON state

ON hole discharged flow rate:
3.2 Stability analysis results
Results

- Less detailed "standard" model of pump in GT-Suite environment
- Transient speed ramps (30 - 40 s realistic speed ramps as in tests) simulated in feasible time
- No VOPs specific models in GT-Suite
- No porting plate
- No clearances
- No rotor chamber dynamics
- No internal pump forces due to hydraulics
Results

- 30 s speed ramp in 5W30 @ 100°C from 0 rpm till 7000 rpm
- Stable actual pump configuration: no oscillation visible in the time pressure signals
- The map plot shows the pump speed at which oscillation begins
Results

- Oscillation appears at a certain pump speed during speed sweep test when some parameters of the pump are changed (e.g. control ring slideways widths in the example)
3.3 Priming analysis results
Results

0-1500 RPM 20 s ramp

Average pressure [Bar] @outlet

Eccentricity [mm]

Gas volume fraction @outlet

Internal force [N] along eccentricity
Simplified model (to be compared with Simerics PumpLinx® 3D analysis)

- No regulation mechanics: fixed eccentricity ($e_{max}$)
- Only axial rotor clearances considered
- No ball valve
Simplified model (to be compared with Simerics PumpLinx® 3D analysis)

- No regulation mechanics: fixed eccentricity ($e_{\text{max}}$)
- Only axial rotor clearances considered
- No ball valve
- 50 mm long, $\varnothing 13.42$ mm outlet pipe
- $\varnothing 6$ mm outlet orifice ($c_d=0.7$, 0 Bar (rel.) environment pressure)
Pump (self) priming

- Designed to lift oil without filling the pump with liquid
- Partial vacuum creation at pump suction
Conclusions

- The GT model has proved to be an efficient tool for simulating a sliding vane variable oil pump in constant speed, dynamics and priming conditions.

- In-house developed routines integrated the GT potentialities.

- In-house experimental validation allowed to validate sweep speed and transient simulation results.

- 1D CFD priming simulations in GT environment were satisfactorily compared with the 3D CFD model in Simerics PumpLinx® environment.
Thank you for your attention!
OUR HEART BEATS FOR YOUR ENGINE.
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