Modeling of Scroll Compressor Using GT-Suite

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   2.1. Working chamber volumes
   2.2. Dynamic behavior of discharge valve
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3. Result & Validation

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1. Introduction & Motivation

- Consisting of two scrolls (moving or orbiting scroll & fixed scroll)
- Orbiting scroll is connected to the crankshaft
- Orbital motion based working principle
- Gas pockets are formed between two scrolls
- Sucked gas is moved towards the center of the scroll (smaller internal pockets), i.e. temperature & pressure is increased
1. Introduction & Motivation

Compressor development
- Noise caused by discharge gas pulsation
- Compressor efficiency
- NVH issues

3D CFD Simulation - Challenges
- Fluid & structural interaction → coupled simulation
- Moving mesh technique
- Highly technical/computational challenges
- Very time consuming

1D System simulation approach:
- Discharge valve optimization → over compression reduction, efficiency improvement
- Muffler system optimization → Gas pressure pulsation reduction (NVH)
- Lower computation time → try-out time reduced, speed —up design process
- Reduce the need of test bench measurement
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2.1. Working chamber volume – different between G2, G3, R744

- Scroll geometries are different – resulting in different chamber volume profiles
- Time for one working cycle: suction – compression - discharge is different
- Working chamber volume can not explicitly describe as a mathematical function
- Opening area of the discharge hole can not be described as an explicit function. (interpolated calculation – very time consuming- or measurement)

G2

Ending angle (one cycle): 980 deg

G3

Ending angle: 1080 deg

CO2

Ending angle: 1090 deg

➤ Model development for each compressor generation
2. Scroll compressor modelling

2.1. Working chamber volume

- Very important input parameter → Need to be modeled properly
- Working chamber volumes are automatically generated by using the Sanden’s simulation tool
- 6 chambers totaly, 3 chambers for each side are separately modelled (GEN2, GEN2 Evo)
- 8 chambers totally, 4 chamber for each side (GEN3, R744)
- Connection between the chambers depending the scroll position is defined
- This approach allows to model different physical phenomenon: leakage, pressure in each chamber....
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2.2. Dynamic behavior of discharge valve

# Reed valve modeling

- One degree of freedom spring-mass system

![Diagram of spring-mass system with damper and labels for stiffness, mass, and damper.]

FE analysis →

Motion equation of valve

\[
\begin{align*}
\frac{d^2x}{d\theta^2} &= \frac{1}{\omega^2} \left( \frac{\Delta P}{m_{eq}} A_d - 2\tau f_n \frac{dx}{d\theta} \omega - f_n^2 x \right) \\
\dot{x} &= f_1(t, x, z) = z = \frac{dx}{d\theta} \\
\dot{z} &= f_2(t, x, z) = \frac{1}{\omega^2} \left( \frac{\Delta P}{m_{eq}} A_d - 2\tau f_n z \omega - f_n^2 x \right)
\end{align*}
\]

- In the simulation model reduced equivalent quantities are used
  - Stiffness
  - Mass
  - Damping coefficient
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2.3. Muffler chambers

# To reduce the compressor noise caused by discharge gas pulsation
# NVH issue

- 3D geometry of muffler chambers are considered by volume discretisation
- Connecting channel between chambers are modeled using orifice system
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2.4. Gen 2 Simulation model development: Chamber Volume
2.4. Gen 2 Simulation model development: Discharge Valve
2. Scroll compressor modelling

2.4. Gen 2 Simulation model development: Muffler
2. Scroll compressor modelling

2.4. Gen 2 Simulation model development

Input Data
- Working chamber volume & Seal-off timing profiles
- Discharge valve characteristics
- Pressure and temperature boundary conditions
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3. Results & Validation – Gen 2

# Following points are considered to validate the simulation model
1. Indicator diagram
2. Valve motion
3. Mass flow rate, cooling performance, power consumption
4. Pressure pulsation

# Tested Operating Conditions
- Speed [RPM]: 3000, 5000, 7000
- Suction Pressure [bar]: 3
- Discharge Pressure [bar]: 15, 20, 25

# Valve Parameters
- Discharge Port Diameter [mm]: 10
- Valve Thickness [mm]: 0,254
- Valve Length [mm]: 15,2
- Valve Max. Lift [mm]: 2,5
- Equivalent Mass [g]: 0,167
- Valve Stiffness [N/m]: 677
- Eigenfrequency [Hz]: 320
3. Results & Validation: Gen2 Evo

# Indicator Diagram – 3000 RPM

- **Pd/Ps = 15/3**
  - Simulation
  - M-I
  - M-II
  - M-III

- **Pd/Ps = 20/3**
  - Simulation
  - M-I
  - M-II
  - M-III

- **Pd/Ps = 25/3**
  - Simulation
  - M-I
  - M-II
  - M-III

Pressure Sensors
3. Results & Validation: Gen2 Evo

# Discharge pulsation: \( \frac{P_d}{P_s} = 10/3 \)  

<Test results_SGB bench>
3. Results & Validation: Gen2 Evo

# Discharge pulsation: \( \frac{P_d}{P_s} = 20/3 \)  

(Test results_SGB bench)
3. Results & Validation Gen3 – Valve Lift

Correlation of the indicator diagram & discharge valve motion between simulation and test data is relatively good.
4. Summarization & Further development

✓ Simulation model for scroll compressor including discharge valve and muffler system is developed which is enables to predict:

✓ The indicator diagram including over compression
✓ The discharge valve motion
✓ The pressure pulsation

✓ Important parameters i.e. indicator diagram, pressure pulsation (@Gen2) is validated

# Outlook:
- Improve behavior of the Discharge Valve
- Validate acoustics behavior of the muffler
- Develop a model for CO2 compressor
Thank You For Your Attention