FME HighEFF

Centre for an Energy Efficient and Competitive Industry for the Future

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Modelling of mechanical and flow processes in compressors

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SINTEF Energy AS

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Abstract

The presentation is a redacted/extended version of the presentation given to Mayekawa in Skype meeting on 13.12.2018. It is redacted in that confidential details are removed. It is extended in that the first slides about background and 1D modelling have been added.

The presentation gives an overview of the three approaches to modelling of piston compressor processes that are being followed: the 1D model, the 3D CFD model, and the 3D FEM impact model.

These modelling approached give complementary insights into the piston compressor processes and will shed light on how to optimize compressors for increased efficiency and reliability.

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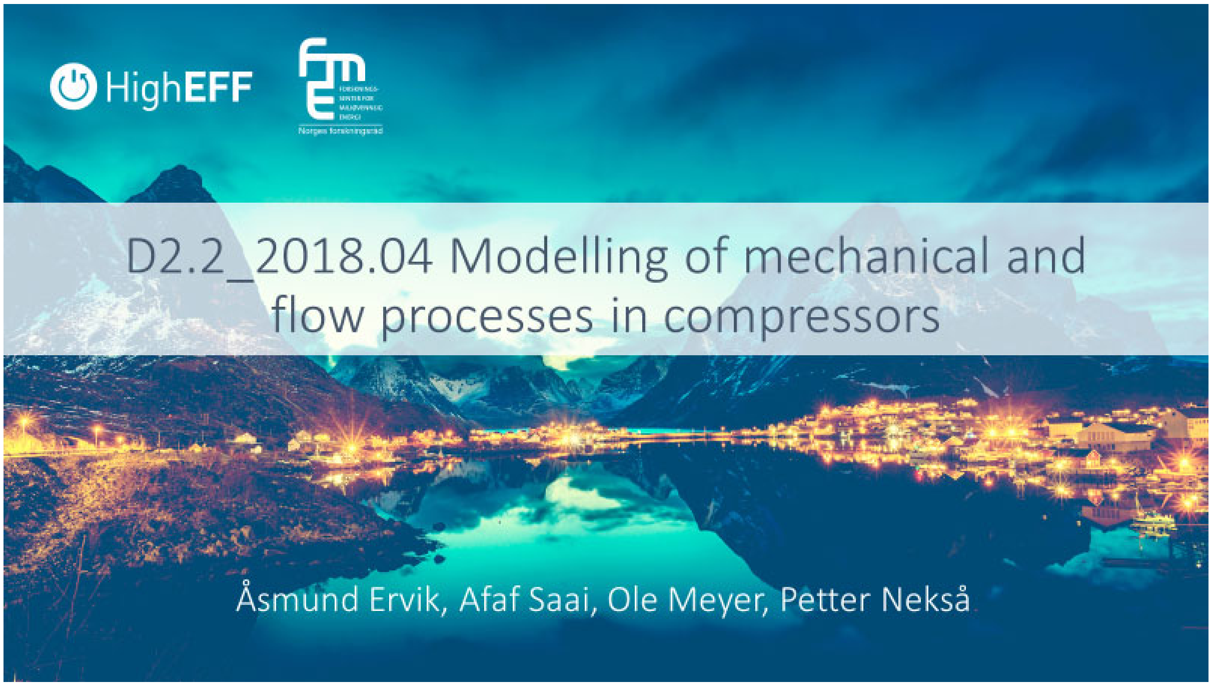
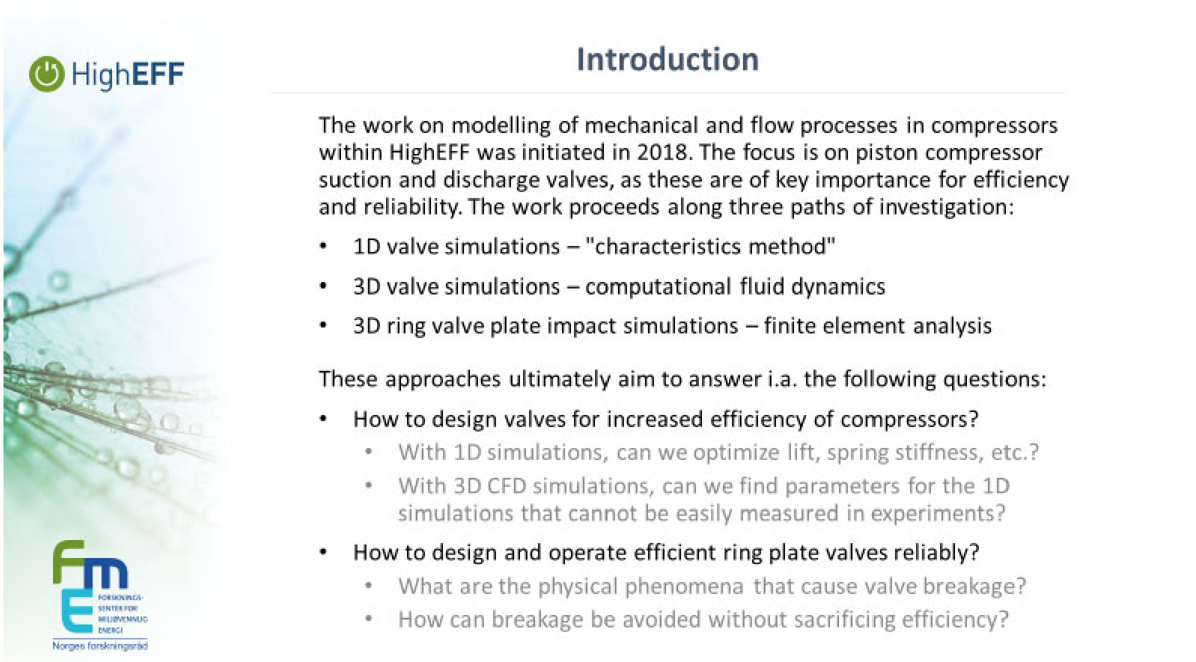
1 Presentation on piston compressor modelling





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1D valve simulations

1D valve simulations using the "characteristics method" was pioneered in the 1980s by the refrigeration technology group at NTNU/SINTEF, Arne Bredesen. Dorin is now interested in this topic for optimization of reed valves in compressors which are under development.

The technique and the code has been "dusted off" and is being updated to take advantage of the latest developments in thermodynamical models.

The primary equations which were solved in the original method were

- Mass flow in/out of the cylinder
- Temperature change of the gas in the cylinder, using some linearisation
- Newton's equations of motion for the suction and discharge valves

Together with the numerical advancement of these equations in time using a Runge-Kutta method, auxiliary equations give

- The pressure of gas in the cylinder
- The density of the gas in the cylinder

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The primary equations which are solved in the updated method are

- Mass flow in/out of the cylinder
- Entropy transport in/out of the cylinder
- Newton's equations of motion for the suction and discharge valves

Together with the numerical advancement of these equations in time using a Runge-Kutta method, auxiliary equations give

- The temperature of gas in the cylinder
- The pressure of gas in the cylinder
- The density of the gas in the cylinder

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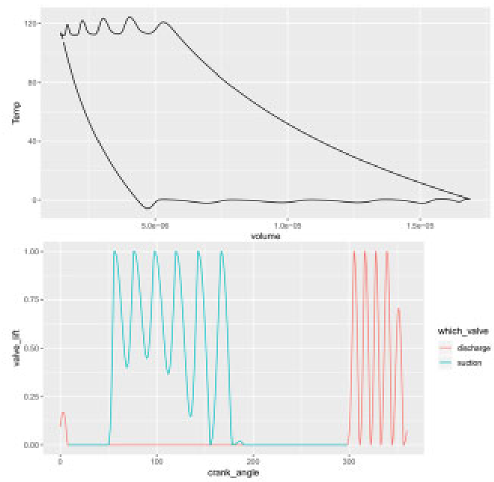
1D valve simulations

An example of preliminary results given by the 1D simulations is shown to the right.

The top figure shows temperature versus volume in a cycle, with the suction temperature of 0 C, and the discharge temperature of 120 C.

The bottom figure shows the lift of the valves versus crank angle. It is seen how the valves oscillate between open and closed.

Work is ongoing on finding a suitable testcase to check input parameters versus old results to see that these can be reproduced.



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3D valve simulations

According to wishes from the industry, specifically Mayekawa Mfg. Co., work is being carried out on three-dimensional ring plate valve simulations. This includes both the CFD and FEM analysis.

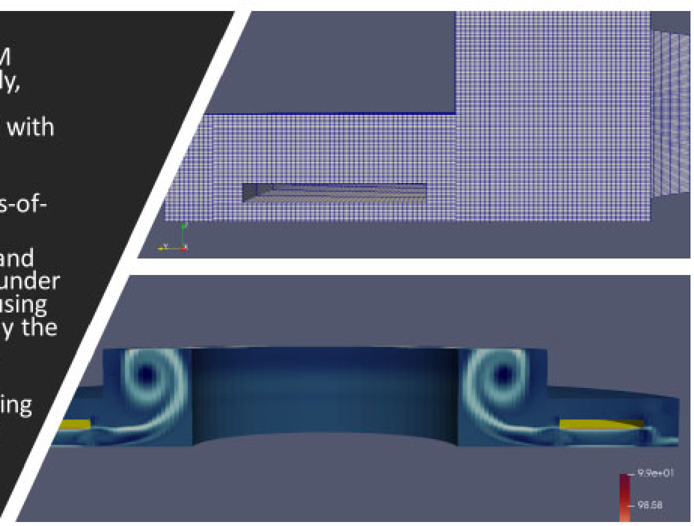
These simulations aim to illuminate the behavior of the ring plate in the discharge valve during one cycle of the compressor. The lift, velocity, pressure drop, and any deviation from perfectly flat ring motion due to the gas flow can be studied with CFD. The impact stress and strain, and the motion due to impact forces, can be studied with FEM.

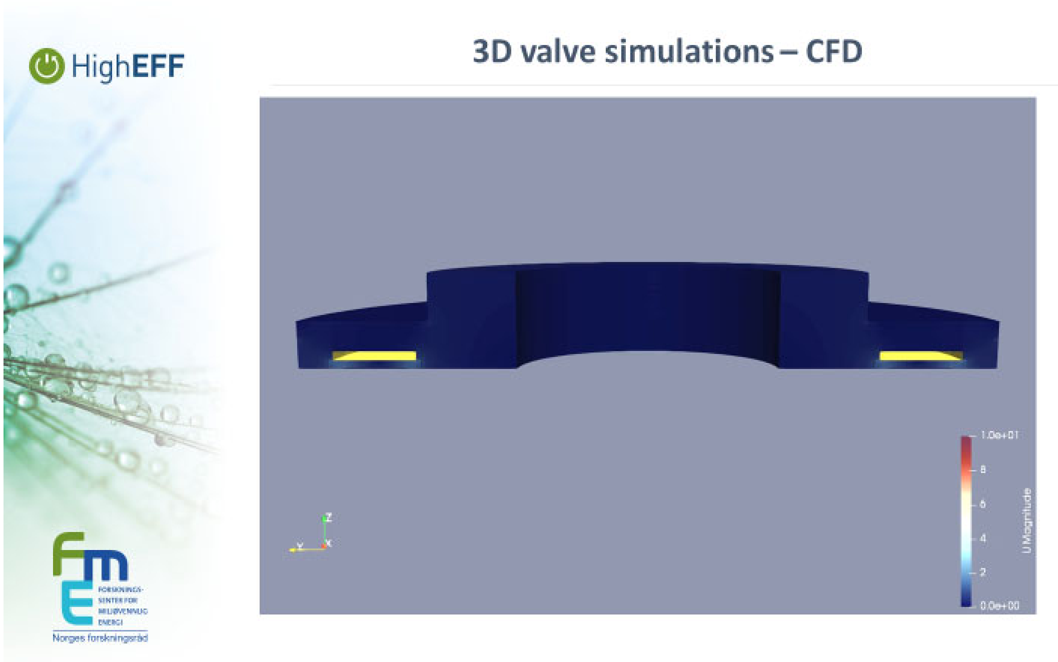
In parallel with the HighEFF activity, SINTEF and Mayekawa have started an industry project where the work is extended to simulate specifically the behavior in the confidential geometry and operating conditions of Mayekawa's R717 compressors.

In 2019, we plan to deliver a joint scientific paper on these simulations, using a "sufficiently simplified geometry" which does not contain confidential details and is thus publishable.

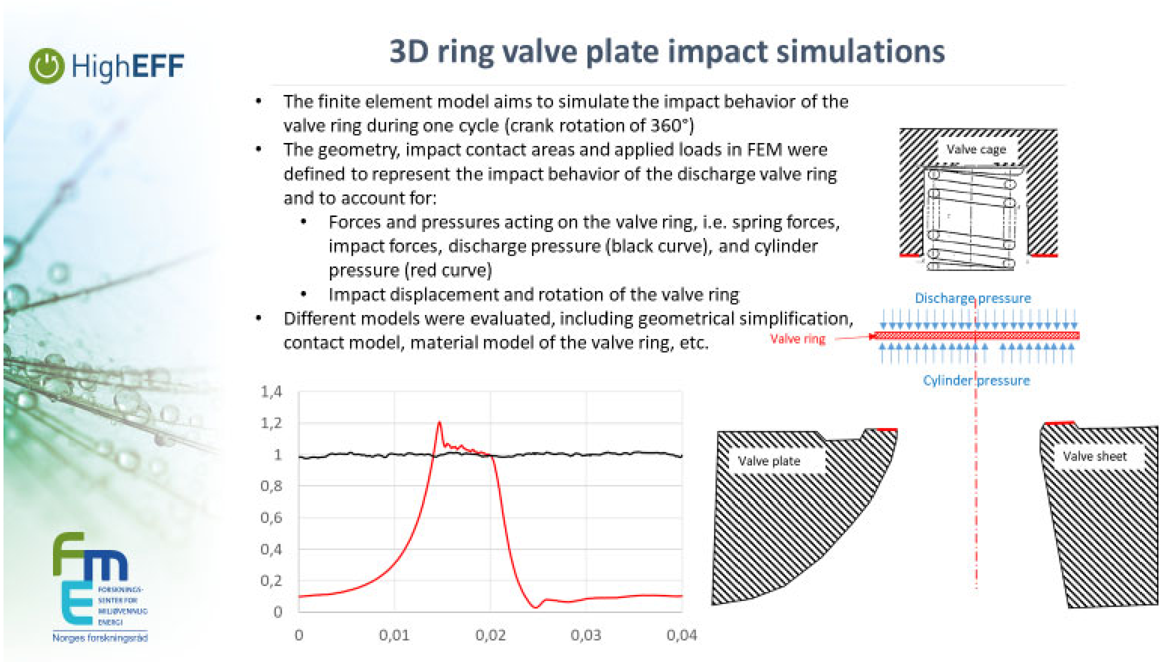
3D valve simulations – CFD

- The CFD simulations use OpenFOAM with the PIMPLE transient solver family, using either incompressible fluid (for testing) or compressible gas (realistic) with Peng-Robinson equation of state.
- The ring plate motion is studied by dynamic mesh motion and six-degrees-of-freedom capabilities of OpenFOAM.
- The mesh is structured hexahedral and aligned with the boundaries. Work is under way in the direct industry project on using OpenFOAM's snappyHexMesh to apply the actual valve geometry from CAD files.
- Next slide: video showing velocity magnitude and plate motion. Oscillating inlet flow below the yellow plate, and outlets at top and outer perimeter.





(Video in presentation showing animation of the plate motion and gas velocity)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3D ring valve plate impact simulations
• The finite element model aims to simulate the impact behavior of the valve ring during one cycle (crank rotation of 360°)
• The geometry, impact contact areas and applied loads in FEM were defined to represent the impact behavior of the discharge valve ring and to account for:
• Forces and pressures acting on the valve ring, i.e. spring forces, impact forces, discharge pressure (black curve), and cylinder pressure (red curve)
• Impact displacement and rotation of the valve ring
• Different models were evaluated, including geometrical simplification, contact model, material model of the valve ring, etc.
Valve cage
Discharge pressure
Valve ring
Cylinder pressure
Valve plate
Valve sheet
1,4
1,2
1
0,8
0,6
0,4
0,2
0
0
0,01
0,02
0,03
0,04
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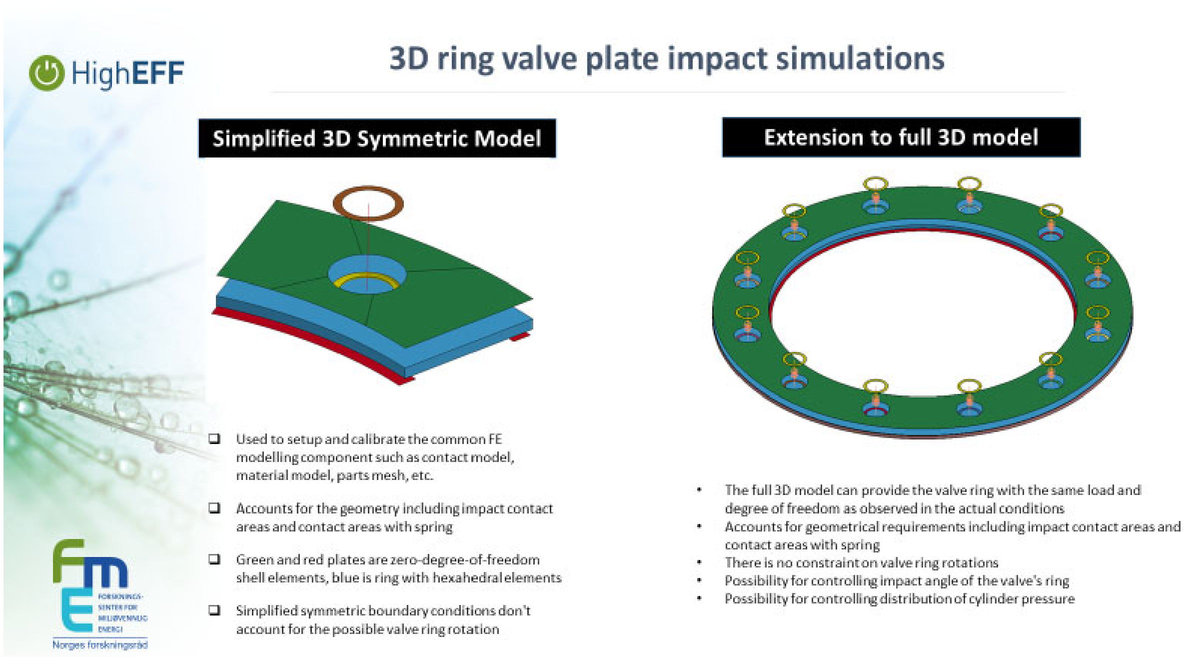
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3D ring valve plate impact simulations
Simplified 3D Symmetric Model
Extension to full 3D model
❑ Used to setup and calibrate the common FE modelling component such as contact model, material model, parts mesh, etc.
❑ Accounts for the geometry including impact contact areas and contact areas with spring
❑ Green and red plates are zero-degree-of-freedom shell elements, blue is ring with hexahedral elements
❑ Simplified symmetric boundary conditions don't account for the possible valve ring rotation
• The full 3D model can provide the valve ring with the same load and degree of freedom as observed in the actual conditions
• Accounts for geometrical requirements including impact contact areas and contact areas with spring
• There is no constraint on valve ring rotations
• Possibility for controlling impact angle of the valve's ring
• Possibility for controlling distribution of cylinder pressure
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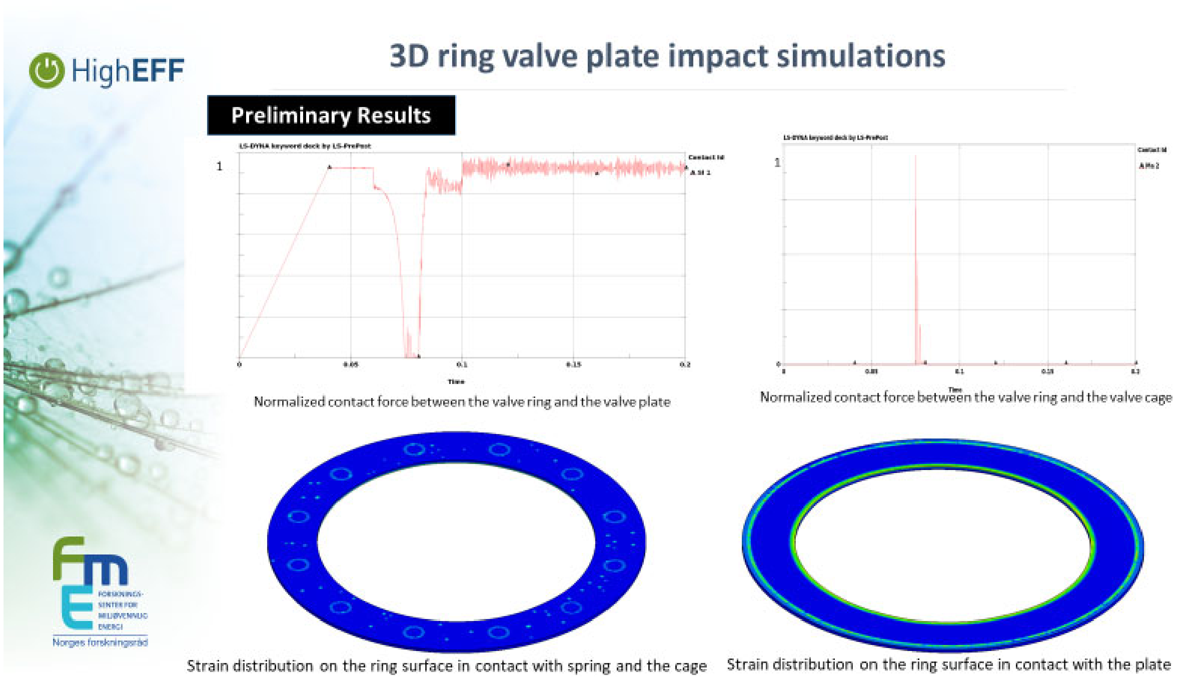
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3D ring valve plate impact simulations
Preliminary Results
Normalized contact force between the valve ring and the valve plate
Normalized contact force between the valve ring and the valve cage
Strain distribution on the ring surface in contact with spring and the cage
Strain distribution on the ring surface in contact with the plate
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