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Getting the most out of pumps and compressors

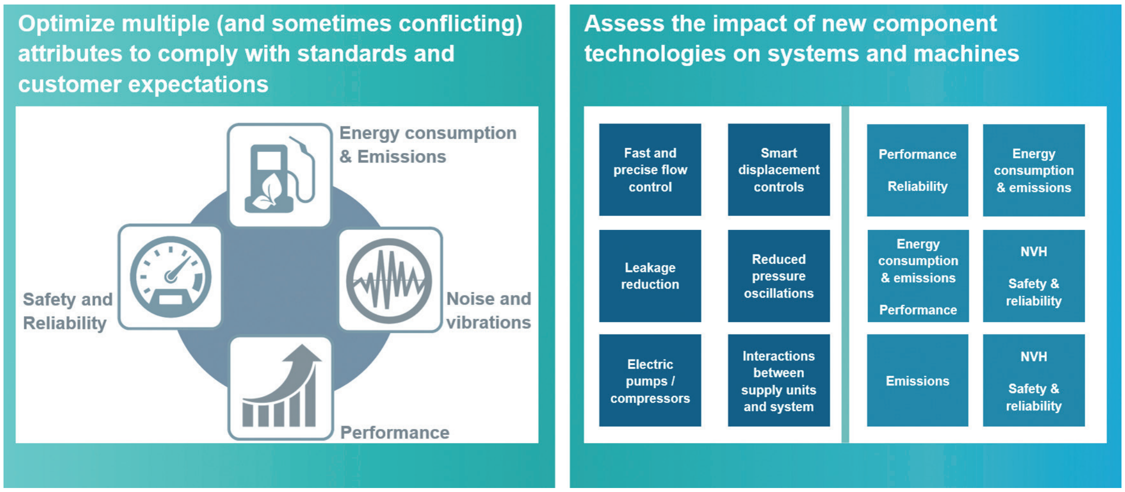
Using Simcenter Amesim to efficiently meet regulatory and market requirements

Executive summary

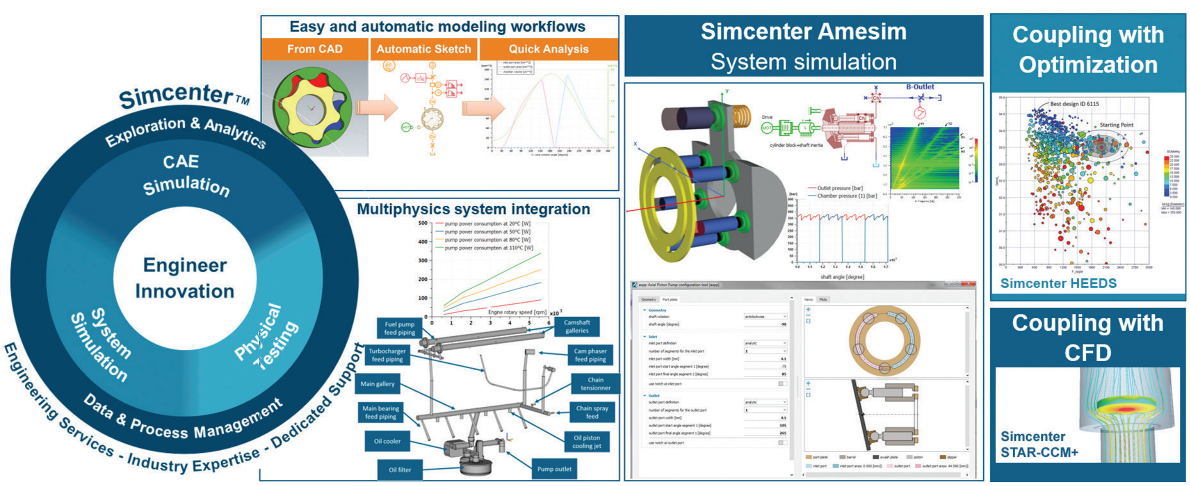
Nowadays rotary machinery suppliers need to satisfy a variety of criteria such as increasing regulations for noise, vibration and harshness (NVH), emissions and safety and reducing energy consumption while maintaining performance. In this challenging context, system simulation solutions can support customers in correctly assessing design choices as early as possible in the development process.

Consequently, new technologies are designed and benchmarked by adopting reliable virtual models that explore the full design space to meet both regulations and customer expectations. Multiple and sometimes conflicting attributes for pumps and compressors need to be satisfied with technical solutions that lead to reduced pressure and torque oscillations, fast and precise flow regulation. Further, interactions between the pumps/compressors and components and systems downstream must be understood.

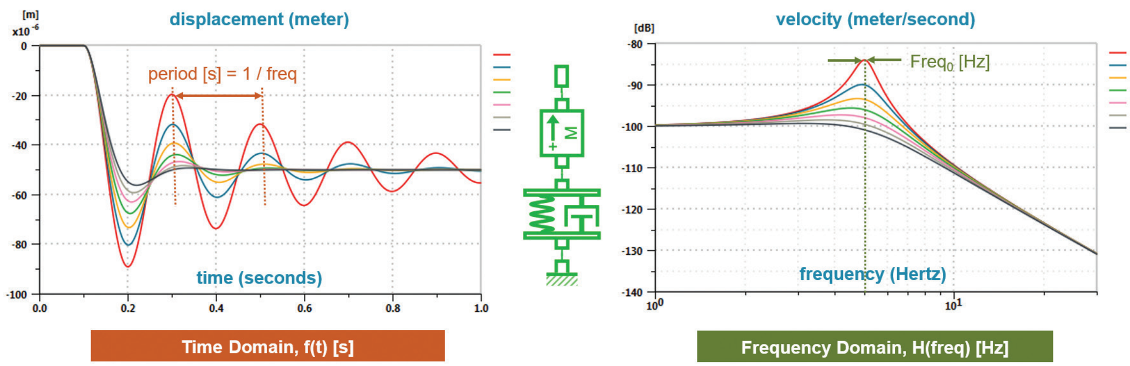
Abstract



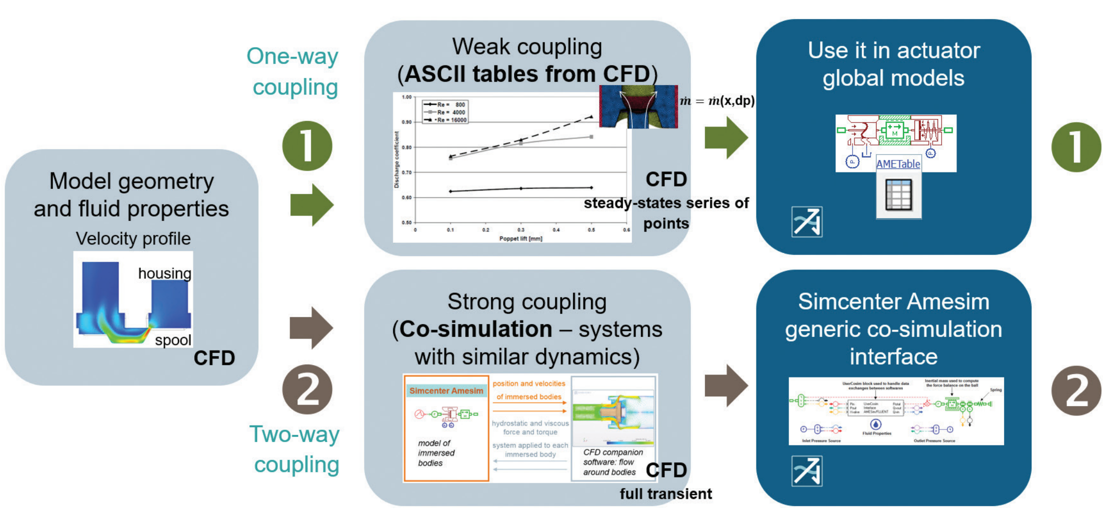
In order to support fluidics component suppliers in developing high-quality products in a reduced development cycle while containing costs, Simcenter™ Amesim™ software, which is part of the Xcelerator™ portfolio, the comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software, offers multiphysics libraries in an integrated environment to represent different physical domains, including mechanics, electrics, hydraulics and thermal.



Complementary to time-domain simulations, frequency-domain tools in Simcenter Amesim allow you to identify free and forced responses such as eigenvalues and natural modes, root locus and Bode/Nyquist/Nichols plots to investigate amplitudes and phases of transfer functions between input variables (for example, the pump ripple excitation) and observers (for example, pressure levels within the circuit).



Simcenter Amesim is fully suited to address all the simulation needs for product development, including functional to detailed geometry-based models and quasi-static to full dynamic physics. Moreover, the openness of Simcenter Amesim allows you to couple system simulation models with 3D computation fluid dynamics (CFD) tools for analyzing fluid flows at local scale. Some applications include evaluating pressure losses in complex piping or grooves, flow coefficients in specific restrictions or flow forces acting on poppet/spool valves with particular flow passages and recirculation.

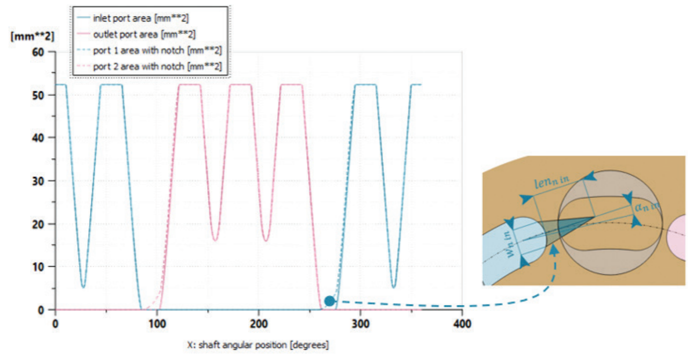


Hydraulic modeling

For hydraulic applications, Simcenter Amesim offers three libraries to satisfy simulation needs depending on available input data and dynamics:

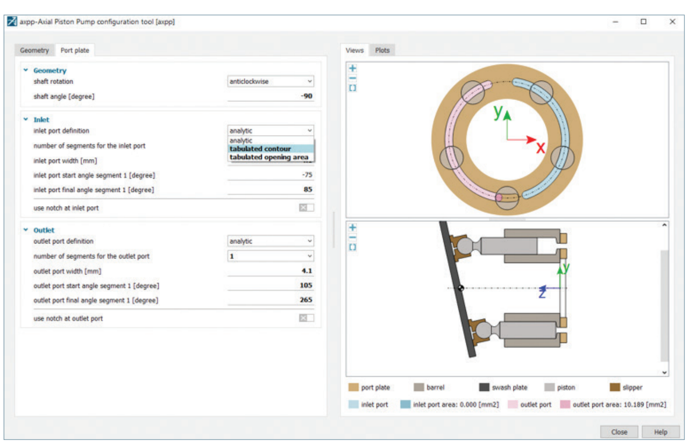
- Functional physical models for overall/prevailing behaviors at the system level for pumps, valves, accumulators, etc., described by common characteristics available on data sheets
- Hydraulic resistances to consider local pressure losses due to bends, T-junctions and other sudden geometry changes in piping. This library could be required for hydraulic pipes at the low-pressure inlet of pumps, where high flows can induce negative relative pressures and strong aeration and cavitation at the suction.
- For complex pipe geometries, engineers can easily build and parametrize the Simcenter Amesim model using the computer-aided design (CAD) import capabilities within the simulation platform
- Finally, the component design library includes many geometry-based models to fully represent flow paths in hydraulic spools and poppet valves, leakages and pumps. This library is suited for component design and optimization of hydraulics

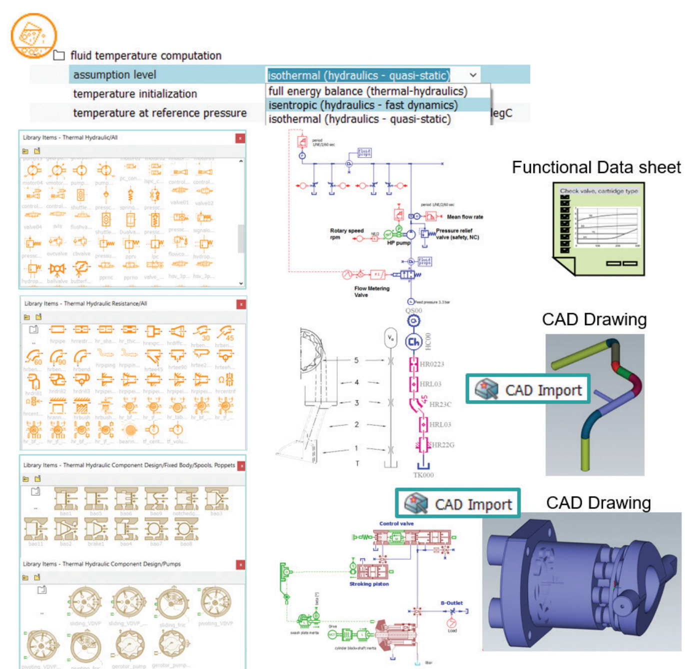
For positive displacement pumps, fully integrated models can be used in the predesign phase when the CAD drawing is not yet available to benchmark different geometry choices with the support of preprocessing apps to facilitate the model parametrization.



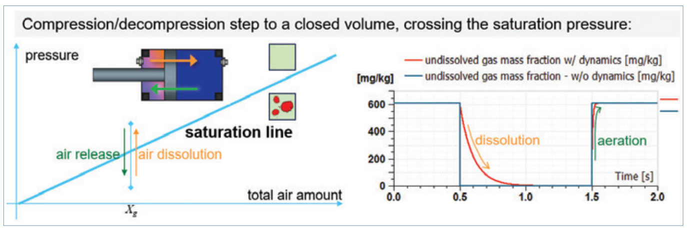
As soon as the pump drawing is available, the CAD import capabilities allow the user to automatically generate the sketch and parametrize the pump model by directly retrieving its geometry.

Computing advanced fluid properties must always respect the mass and energy conservation thermodynamic principles, thus allowing you to predict aeration and cavitation phenomena that might occur, as an example, at the pump inlet at higher angular speeds.

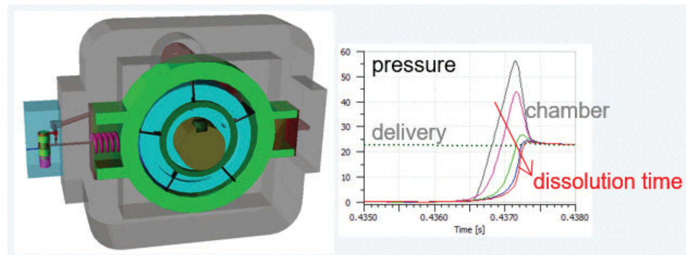




With the most complex aeration model suitable for full dynamics analysis in hydraulic pumps, the total and undissolved air amount are independent variables computed from the mass fractions conservation laws. The evolution of undissolved gas mass fraction considers dynamics for aeration and dissolution by either considering a first order lag characterized by user-defined time constants or more complex laws.[1]



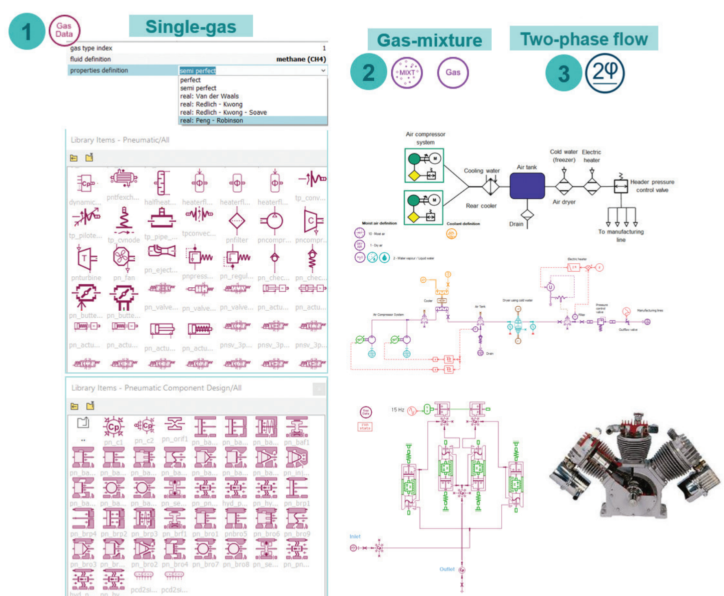
This paper[2] shows the impact of air dissolution dynamics on the regulation of a variable displacement lube pump with adjustable pressure setting. These dynamics have a strong influence on the instantaneous amount of separated air, which in turn determines the value of the effective bulk modulus of the air/oil mixture and the pressure evolution rate.



Pneumatic modeling

Simcenter Amesim offers libraries to satisfy different pneumatic simulation needs depending on available input data and dynamics to be represented.

- For applications with a single gas, the pneumatic libraries can deal with perfect, semi-perfect and real gas properties
- The gas mixture solution is suited to several species with time evolution of gas fractions
- In the case of two-phase flow, specific libraries are available to analyze the fluid phase-change phenomenon in evaporators or condensers



Application examples

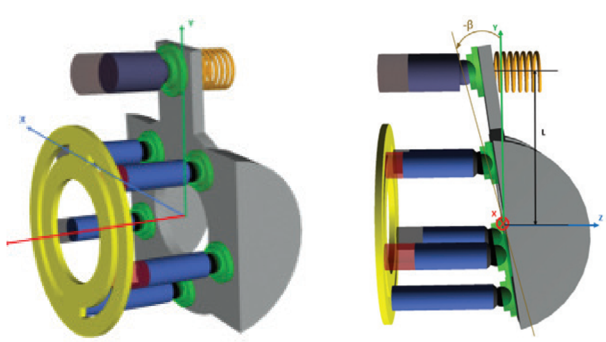
Among all possible pump and compressor technologies used in all the different industry segments, this section focuses on an axial piston pump and a reciprocating compressor.

Axial piston pump

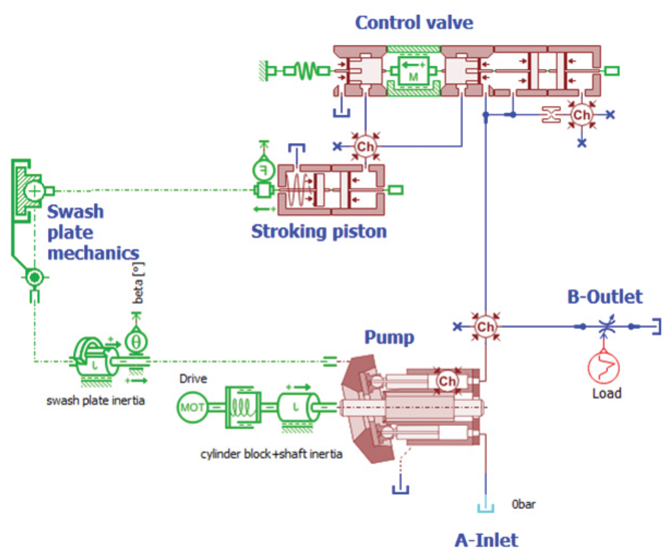
Axial piston pumps are widely used throughout the mobile and industrial sectors, as well as to power hydraulic systems of jet aircrafts. This technology can reach high volumetric efficiencies even at the highest hydraulic pressures; moreover, axial piston pumps lend themselves to fixed or variable designs.

The following picture shows a variable displacement axial piston pump with swash plate design.

As soon as the pump delivery pressure reaches a maximum value corresponding to the cracking pressure of a control valve, then the stroking piston acting on the swash plate starts being pressurized and moving in a way (from the left to the right) to reduce the swash angle β and then the pump displacement and flow rate.



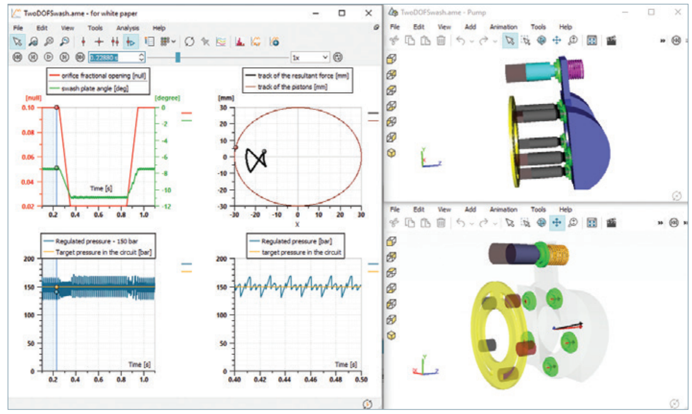
The pump model has been automatically generated and parametrized importing the CAD file directly into Simcenter Amesim. Additionally, the control valve, stroking piston and swash plate mechanics have been added to realize the swash plate regulation to reduce the pump displacement when the delivery pressure reaches the value equivalent to a spring preload.



The pump model integrates many phenomena that affect it, such as:

- The kinematics of the pump pistons
- The port-plate opening areas (which might include notches)
- Internal leakages and viscous friction forces and the fluid compressibility strongly increasing when aeration and cavitation phenomena occurs, particularly at the highest shaft speeds

The above simulation model allows the user to optimize the pump design to reduce flow and torque ripples, improve NVH characteristics and efficiency and guarantee a stable regulation of the displacement in the full operational range.



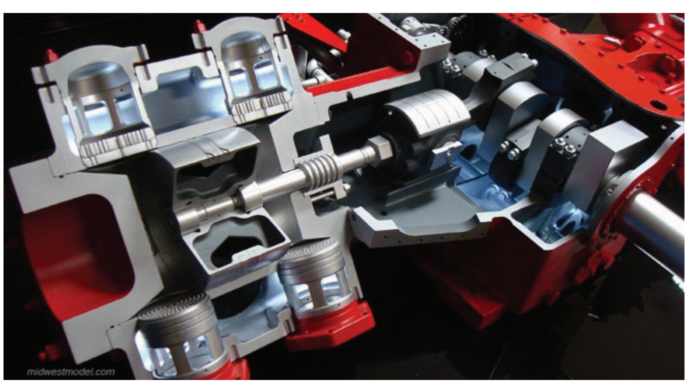
There are many papers available that cover the use of Simcenter Amesim for axial piston pump design and optimization.[3, 4, 5, 6, 7]

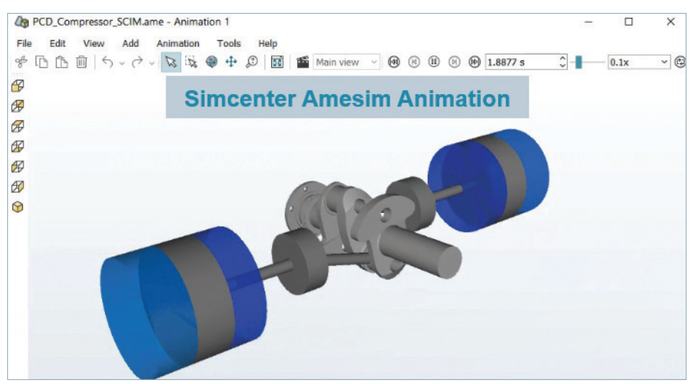
Reciprocating compressor

A reciprocating compressor is a positive-displacement machine with stroking pistons to compress a gas and deliver it at high pressure. The pistons are driven by a crank mechanism.

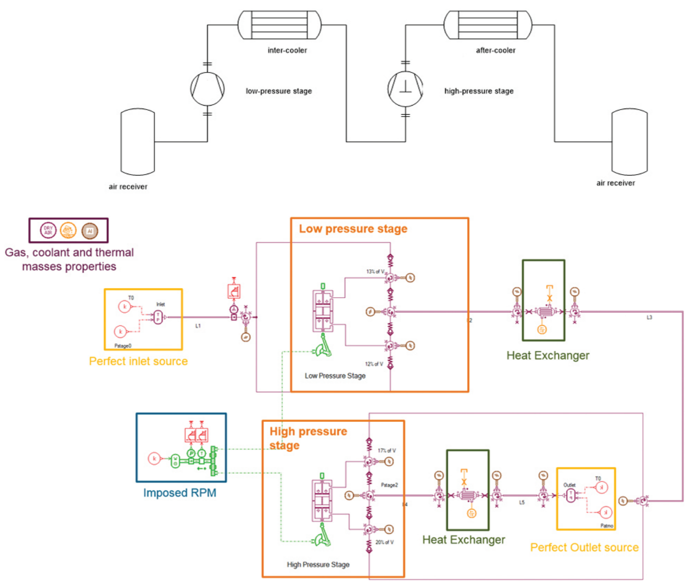
Compressors are found in almost every industrial plant to generate compressed air for different machining tools, for gas storage and transmission systems and in the oil and gas industry. They may be a single- or dual-acting design. The characteristic of dual-acting designs is the compression occurs on both sides of the piston during both the extension and retraction.

In case of high compression ratios, multiple stages of compression are realized with multiple compressors working in series. During compression the temperature increases rapidly, hence heat exchangers need to be sized proportionately to avoid overheating.



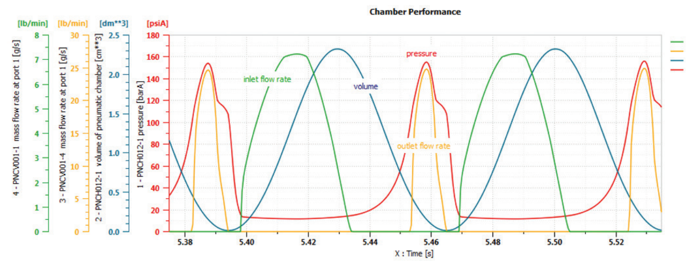


The current Simcenter Amesim application shows a dual-acting compressor with two stages and two heat exchangers (inter and after-cooler) for temperature cooling.

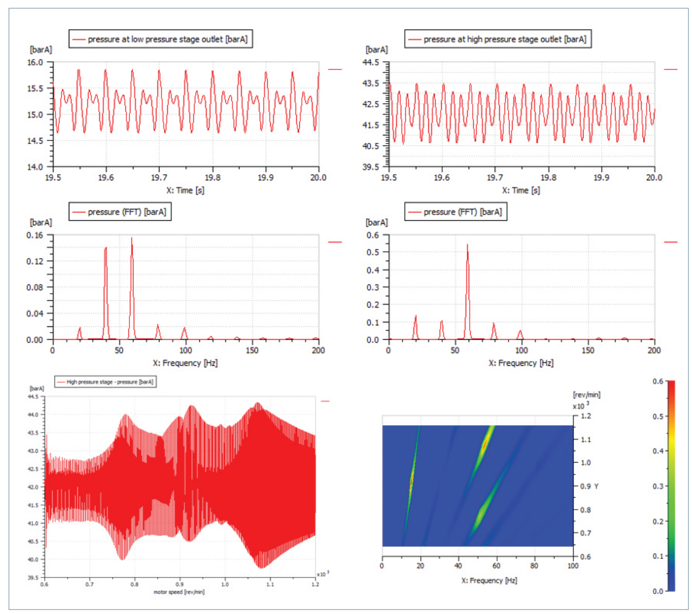


The above simulation model allows the user to improve the compressor performance by predicting torque demand, understanding gas line dynamics, reducing pumping losses (friction, leakage) and improving the compressor driveline dynamics (modal shapes, frequency response).

Simcenter Amesim enables users to evaluate the performance of each chamber in terms of volume variation, inlet and outlet flowrates and internal pressure.



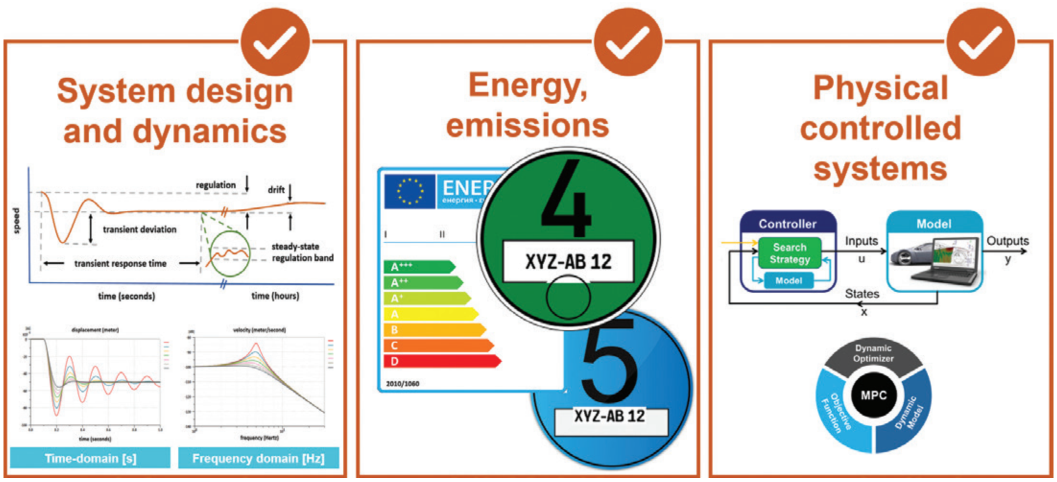
At the outlet of each compression stage users can verify the temperature level, pressure pulsations and the influence of pneumatic lines on the damping or amplification of these oscillations.



Conclusion

Simcenter Amesim provides modeling support for fluid components that deliver high performance and smart mechatronic systems while keeping development time and costs under control.

System simulation helps engineers achieve proper sizing and optimization of the dynamic performance of fluid supply units, valves, heat exchangers, actuators and other connected components. It also facilitates the modification of existing or new designs at early stages by enabling you to verify thermal behavior under different operating conditions and operating cycles and integrate smart control strategies from the beginning of the product design cycle.



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Siemens Digital Industries Software

Headquarters
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 972 987 3000

Americas
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 314 264 8499

Europe
Stephenson House
Sir William Siemens Square
Frimley, Camberley
Surrey, GU16 8QD
+44 (0) 1276 413200

Asia-Pacific
Unit 901-902, 9/F
Tower B, Manulife Financial Centre
223-231 Wai Yip Street, Kwun Tong
Kowloon, Hong Kong
+852 2230 3333

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