Steady State Initialization of Vapor Compression Cycles Using the Homotopy Operator

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Modelica is nowadays widely used in industry and research for object oriented modelling and transient simulation of cyber physical systems. Several Modelica compilers are available and the compatibility between them is continuously improving.

Although Modelica is used for transient simulation of dynamic models, the user is often only interested in the steady state results. And even if the transient simulation is wanted, the initial state of the model is preferred to be in steady state.

Vapor compression cycles are computationally very expensive. The fluid properties used in these models are highly nonlinear and based on complex equations (multiparameter equations of state). The fluid properties also have a very limited numerical range of validity, e.g. evaluating these properties for a negative pressure, temperature or density is impossible. As the equations have been estimated to describe measurement data, they also have an even more restrictive physical range of validity. So it is essential that the system state always is within the range of validity.

Homotopy is a concept to increase the robustness and simplify the solving procedure for algebraic nonlinear systems. The idea is to use a simplified model (to replace complex dependencies by simplified ones), to calculate a first guess for the result of the actual equation system, and to make use of the similarity of the systems during the transition from the simple to the complex equation system.

We are focusing on finite volume models with balance equations for mass, energy, and momentum. Some components such as the valve and compressor have steady state balance equations. The dynamic heat exchangers are dicretized one-dimensionally. If the dynamic component models shall be initialized in steady state, then an additional initial equation has to be added to set the time derivative of the continuous time state to zero.

The basic concept for the simple equation system is to describe the state of a whole vapor compression cycle using a number of simple conditions:

- Fixed heat flow rates in each heat exchanger
- Fixed mass flow rate and power in the compressor
- Fixed pressure and filling level in the separator
- Linear characteristic in the valve

For this simplified nominal working state, all mass flow rates, enthalpy and pressure states can be calculated.

To evaluate the homotopy concept, a common R-134a automotive vapor compression cycle is examined. The whole system including the controllers is initialized in steady state. All results have been calculated using Dymola 2019.

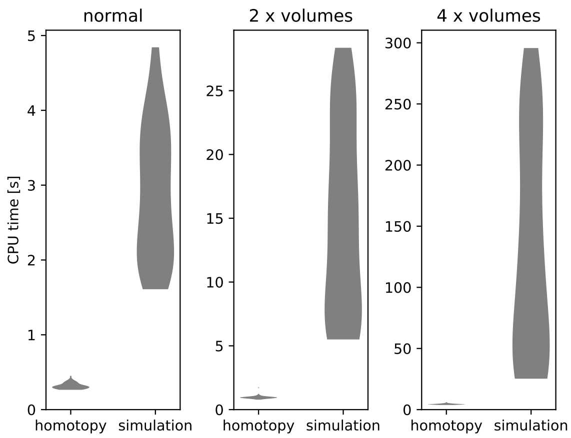

Figure 1. CPU time of a parameter variation compared between simulation with Dassl (tolerance = 1e-4) and homotopy initialization. "2 x volumes" indicates that the number of control volumes has been doubled compared to the normal example. The thickness of this violin plot indicates the density of occurrence.

In figure 1 the CPU times for the different cases are shown. For the three variations (three levels of dicretization) of the system homotopy method is computationally less expensive than a simulation by a factor of 5-10.

The simplified equation system to describe a vapor compression cycle that was presented in this paper is easy to parametrize, and defines a reasonable system state. The simple model is very abstract but it particularly enables separation of different flow paths and different cycles, so it is potentially able to handle large scale problems, even though this still has to be proven.

The experiments show that initialization using the presented approach is very robust and leads to a reduction of the computational effort.