Liquid Cooling Applications in Twin Builder

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Abstract

This industrial paper introduces the new Liquid Cooling Library (LCL) that is available in ANSYS Twin Builder Heating and Cooling Library bundle. This library is a multi-tool compatible Modelica Library which can help customers to deploy simulation of cooling systems in a new way. In general, LCL can be used for modeling cooling circuits across many industries like aerospace, automotive and process industry. The combination with the extensive electronics and electrical machine libraries in Twin Builder makes LCL a natural fit for cooling of power electronics and thermal management of electric vehicles.

Keywords: Twin Builder, Liquid Cooling Library, Optimica Compiler Toolkit, Thermal Management, Electronics Cooling

1 Introduction

Modelica is one of the best and most efficient ways to express physical models that can be used to implement analytical model based systems engineering (MBSE) through modeling and simulation. ANSYS Twin Builder is a powerful platform for modeling, simulating and analyzing system-level digital prototypes. Twin Builder is used in model-based design workflows in automotive, aerospace, electronics, energy and industrial equipment segments to model and simulate multidomain systems. Modelon offers a comprehensive suite of multi-tool compatible libraries powered and built on the Modelica standard through the Modelon Library Suite. Modelon also provides the OPTIMICA Compiler Toolkit, the most advanced Modelica-based mathematical engine on the market through its Modelon Creator Suite. This combination of the leading library portfolio, Modelica compiler and powerful simulation platform has convinced ANSYS to market the Modelon thermal libraries to the industry through its tool Twin Builder. The industry can benefit from off-the-shelf components available for translating their system into models and simulate various real-life scenarios.

Twin Builder Heating and Cooling Library bundles together Modelon's Liquid Cooling Library (LCL), Heat Exchanger Library (HXL) and Vapor Cycle Library (VCL). This paper presents the LCL [4] that can be used to model wide variety of internal flow thermal management, hydraulic sizing and temperature control applications ranging from automotive and aerospace to industrial equipment and process industry.

2 Twin Builder

ANSYS Twin Builder helps customers improve Predictive Maintenance outcomes - allowing one to save on warranty and insurance costs and optimize their product operations.

To easily and quickly build, validate and deploy digital twins - virtual replicas of a physical system - ANSYS Twin Builder provides a variety of capabilities. To build the twin, ANSYS Twin Builder combines the power of a multi-domain systems modeler with extensive 0-D application-specific libraries, 3D physics solvers and Reduced Order Models (ROM) capabilities along with embedded software development tools, allowing system developers to reuse existing components and quickly create a systems model of their product. To validate the system, ANSYS Twin Builder combines multi-domain systems simulation capabilities with rapid Human Machine Interfaces (HMI) prototyping, systems optimization and XiL validation tools, ensuring that the system design will perform as expected. And, to connect the twin to test or real-time data, ANSYS Twin Builder easily integrates with Industrial Internet of Things (IIoT) platforms and contains runtime deployment options, allowing customers to perform predictive maintenance on their physical product. ANSYS Twin Builder offers a packaged approach for our customers' digital twin strategy.

Twin Builder's built-in libraries provide a rich collection of components used to create complete system models. The models can be selected from multiple physical domains and multiple levels of fidelity to capture the desired system dynamics at an appropriate level of detail. Twin Builder models are easily parameterized to replicate physical component behavior. Twin Builder libraries include analog and power electronics components; control blocks and sensors; mechanical components; hydraulic components; digital and logic blocks; application-specific libraries for aerospace electrical networks, electric vehicles and power systems; and characterized manufacturers' components. Twin Builder supports the Modelica Standard Library and Modelica libraries offered by Modelon AB, including libraries for hydraulics, pneumatics, liquid cooling, heat exchangers and thermal power.

3 Liquid Cooling Library

LCL is used for modeling and simulation of liquid cooling systems. Both standard and non-standard cooling circuits can be modeled with ease as shown in *Figure 1*. In particular, *Figure 1* illustrates a cooling circuit model of an internal combustion engine. The closed cooling circuits are handled well with this library. It includes more than 80 internal flow components such as pipes, bends and junctions. These components are neatly organized into different packages. These packages as shown in *Figure 2* provide high performance modeling of incompressible flows within closed circuits making the library suitable for real time as well as desktop applications. The usage of incompressible fluid flow assumptions in the library helps in reaching high performance while simulating complex cooling circuits. The library has suitable numerical operators applied in important physics like mass flow conservation and energy balance to make real time computation possible. These operators can be switched ON or OFF by the users.

3.1 Library Content & Structure

As shown in *Figure 2*, the library is divided into several sub-packages for accommodating different component types. In each package, components are readily available for use in system models. In addition to the component packages, there is an Experiments package, which contains several examples of system models that can be simulated. These models should give an idea of how the component models in the library can be used. Also found on the top level of the library is the Media package, which contain definitions of medium property models for coolant.

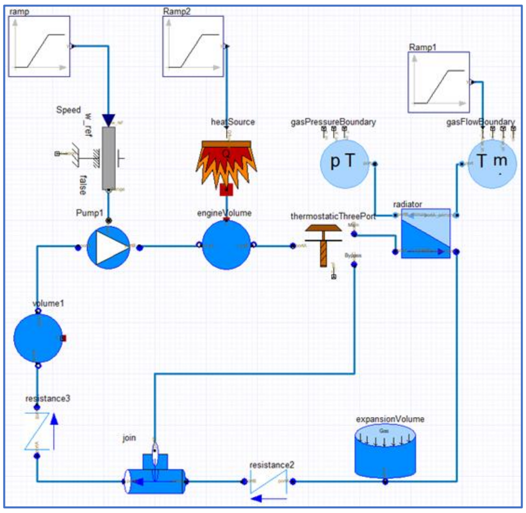

Figure 1. System model built in Twin Builder

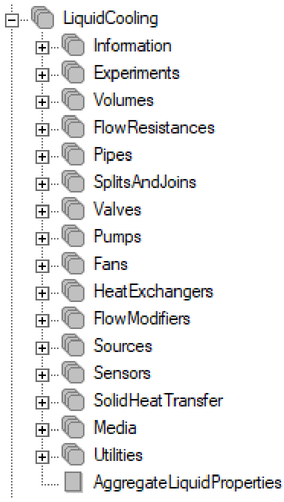

Figure 2. Modelon Liquid Cooling Library Structure

Volumes, flow resistances, pipes, splits and joins and pumps are the packages from which the user can drag and drop any components of interest to build the system model of his choice. Heat exchanger models are available in LCL with the assumption of homogeneous conditions of the inlet and outlet flows and with no phase transitions of the fluids. Simple models of heat exchanger stacks are also available in the library up to 8 heat exchangers per stack.

3.2 Key Assumptions, Features & Capabilities

All liquid models in the library are incompressible. More specifically that means that:

- The liquid density is independent of the pressure
- Volume components have quasi-static mass balances

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- The liquid specific enthalpy is independent of pressure

Compared to compressible fluids there are some fundamental differences when assuming incompressible properties:

- Temperature is the only state variable in control volumes.
- Because of the quasi-static mass balances, the mass flow rate in branches are always the same in all components of one branch.
- For an incompressible fluid system, the mass flow rates in each branch must be given directly by boundary conditions and the state variables.

All the above assumptions make sure that models provides high performance for the system simulation performed by the user. LCL comes with a large set of fluid component models like volumes, a large collection of fluid resistances, pipes, splits & joins, valves, pumps, fans, heat exchangers and fluid properties as shown in *Figure 3*.The fluid resistance elements are based on the complete set of data from reference [1], the de-facto standard guide for the design and analysis of thermos-fluid systems and components. The fluid property models include:

- Water
- Aqueous solutions of glycol, alcohols, glycerol, ammonia, chlorides and salts
- Jet fuels and motor oil

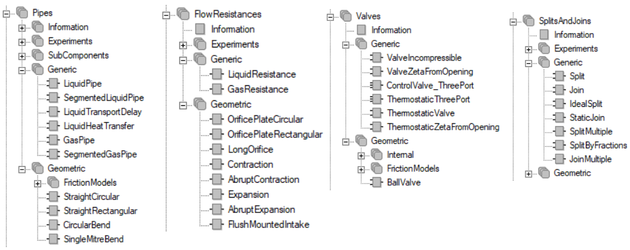
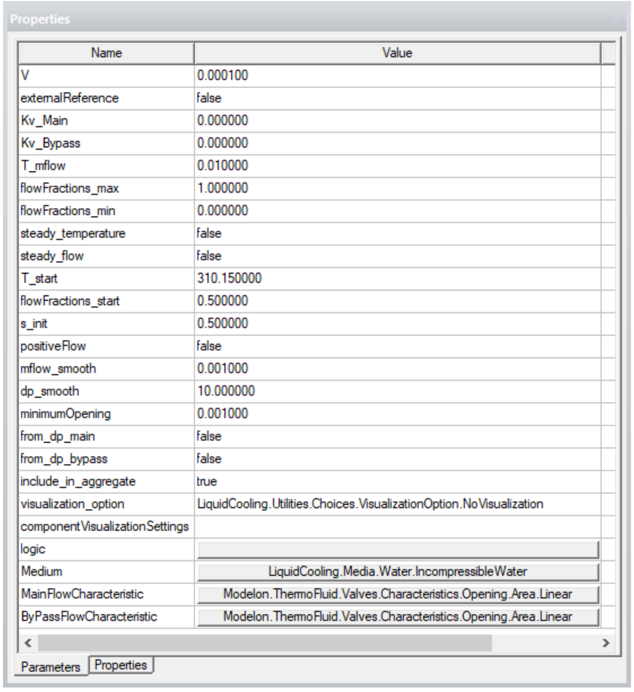


Figure 3. Large set of fluid component models in LCL

All component models come with broad parameterization possibilities. The user is provided with vital geometry, characterization and fluid related parameters through the parameter tab in Twin Builder as shown in *Figure 4*.

It is also possible to study the propagation of trace components in liquid flow networks or circuits. A trace component is a species diluted in the liquid in such low concentration that it can be assumed not to affect the thermodynamic or transport properties. This will be helpful in studying contaminations in the coolant.



Properties

Name	Value
V	0.000100
externalReference	false
Kv_Main	0.000000
Kv_Bypass	0.000000
T_mflow	0.010000
flowFractions_max	1.000000
flowFractions_min	0.000000
steady_temperature	false
steady_flow	false
T_start	310.150000
flowFractions_start	0.500000
s_init	0.500000
positiveFlow	false
mflow_smooth	0.001000
dp_smooth	10.000000
minimumOpening	0.001000
from_dp_main	false
from_dp_bypass	false
include_in_aggregate	true
visualization_option	LiquidCooling.Utilities.Choices.VisualizationOption.NoVisualization
componentVisualizationSettings	
logic	
Medium	LiquidCooling.Media.Water.IncompressibleWater
MainFlowCharacteristic	Modelon.ThermoFluid.Valves.Characteristics.Opening.Area.Linear
ByPassFlowCharacteristic	Modelon.ThermoFluid.Valves.Characteristics.Opening.Area.Linear

Parameters | Properties

Figure 4. Typical parameter tab in Twin Builder

In the Twin Builder environment, cooling system models can be created using a drag and drop approach with very little effort from the user. The capabilities of LCL makes it an ideal candidate for playing a vital role in performing transient system analysis in the following cases:

- Cooling systems for automotive, aerospace, industrial equipment and process industries
- Engine cooling
- Lubrication circuit design
- Battery thermal management
- Component selection
- Pump dimensioning
- Design and analysis of non-standard cooling solutions
- Support of control system development and evaluation

4 Applications / Use cases

The LCL is an important part of libraries required for making vehicle thermal management models for automobiles as shown in [2], [3] and [5]. This can cover a range of vehicles from conventional to electric and hybrid electric vehicles. The cooling system of an internal combustion engine or a traction motor can be created using library's off-the-shelf components as shown in *Figure 1*. *Figure 1* is a dynamic model of a liquid cooling circuit of an internal combustion engine. The coolant flow is driven by a pump incorporating a table-based pump characteristic curve. The external heat load from the engine is approximated by a ramp input signal of heat flow rate. A radiator with a thermostatic bypass valve cools down the liquid coolant. For the radiator, the heat exchanger effectiveness is mapped directly from the mass flow rates of both air flow and coolant flow using a look-up table.

The components as well as the fluids in the Liquid Cooling Library are adapted for the development of cooling systems for power electronics and machines. The library has successfully been used for the analysis of cooling systems in the power electronics of wind turbines. A great number of applications, including engine design in the aerospace industry, require the fuel to act as coolant. In such cases LCL is deployed in an effective manner to model and simulate the systems.

The Liquid Cooling Library contains the relevant pressure drop models, valves and heat exchanger models to accurately represent a district heating network. Careful industrial deployments have resulted in reductions in operational costs by adapting the water supply temperature and intelligent valve control. Overall this library finds applications in a variety of applications starting from aerospace, automotive industries to solar power plants [6].

5 Possibilities

Twin Builder being a tool that covers the entire breadth and depth of physical modeling opens numerous possibilities on the type of studies that can be made through the Liquid Cooling Library. Twin Builder can let the LCL models combine with detailed control element models involving advanced power electronics devices and characterization tools (Semiconductors) along with state-machines and signal flow logic. Twin Builder's strong features like Co-simulation with 3D solvers and reduced order modeling can capture complex multi-physics interactions between the 3D and the 1D systems simulation world captured with Modelica Libraries. Twin Builder also supports Functional Mockup Interface through which models built can shared with many other Simulation tools.

6 References

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