Modelling of Energy Systems with OpenModelica

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Outline

- Recent relevant achievements of OpenModelica
- Coverage of libraries for energy system simulation
- Research & development activities based on OMC (also in partnership with Dynamica srl)
- Conclusions and recommendations for 2015

Recent relevant achievements of OpenModelica

- First-class front-end
  - Almost 100% flattening
  - *Some issues with lookup in corner cases*
  - *Some issues remaining with package constants (Modelica.Media)*
  - *Some issues with lost start attributes set in medium models*

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- Huge progress in the back-end
  - Initial equations handled with full symbolic processing
  - Nonlinear equation tearing
  - Rudimentary support of homotopy() operator
  - Wide choice of integration algorithms
  - *Reliable CSE not yet available*
  - *Some issues with nonlinear solver convergence*

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- OMEdit begins being really usable
  - Vastly improved look&feel of graphical editing
  - Transformational debugger available
  - Full control of compiler options
  - *Replaceable classes not handled (medium & heat transfer models)*
  - *Indentation and formatting not preserved by editor*
    (RCSs support is severely impaired)

Basic building block #1: Modelica.Media

- Most challenging part of the MSL w.r.t. efficient compiler support
  - Complex extends/redeclare involving packages and functions
  - Package constants used throughout
  - Arrays, records, arrays and records within arrays
  - Inline/LateInline/CSE required for proper operation
- 100% Modelica.Media coverage achieved!!
- Essential for the modelling of energy systems based on thermo-hydraulic processes (Rankine and Brayton cycles)

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- 100% Modelica.Media coverage achieved!!
- Essential for the modelling of energy systems based on thermo-hydraulic processes (Rankine and Brayton cycles)
- Issues with package constants
  - Incorrect evaluation of package constants for gas mixtures when using iterators in expressions
  - Inefficient handling of package constants determined by functions (re-evaluated every time instead of just once)
- Medium-defined start attributes sometime lost in translation
  - Essential for reliable initialization of nonlinear solver

Basic building block #2: ExternalMedia

- Medium library interfacing Modelica models with external codes for fluid property computation
- Under development since 2007 using Dymola
- Relies on external functions (not external objects!)
- 100% compatible with Modelica.Media.Interfaces
- Used for thermodynamic cycles with evaporating fluids other than water
  - Refrigeration system
  - Heat pumps
  - Organic Rankine Cycle systems

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- Used for thermodynamic cycles with evaporating fluids other than water
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  - Heat pumps
  - Organic Rankine Cycle systems
- 100% Coverage achieved in Windows and Linux!
  - FluidProp (TU Delft)
  - RefProp (US NIST)
  - CoolProp (Université Liege, open source!)
- Package constants are still not evaluated once and for all

Basic building block #3: ThermoPower

- Developed @ Politecnico since 2002, mainly using Dymola
- Dynamic modelling of power production systems based on thermodynamic processes
- Aimed at control system studies

- Progress since the 2014 Annual Meeting (testsuite logs)

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- Main open issues
  - Full support of CSE to avoid repeated function calls to heavy medium property functions
  - Convergence problems with nonlinear solver
  - Lost start attributes break initialization
  - Proper support of homotopy() strategic for reliable initialization of complex systems

Value of the testsuites for the OSMC

- Large and diverse collections of test cases are essential to develop a strong Modelica compiler
- The testsuite is one of the most valuable assets of the OSMC!
- Great job with automated testing

- One example: tuning the nonlinear solver

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➡ More and more diversified libraries in the testsuite

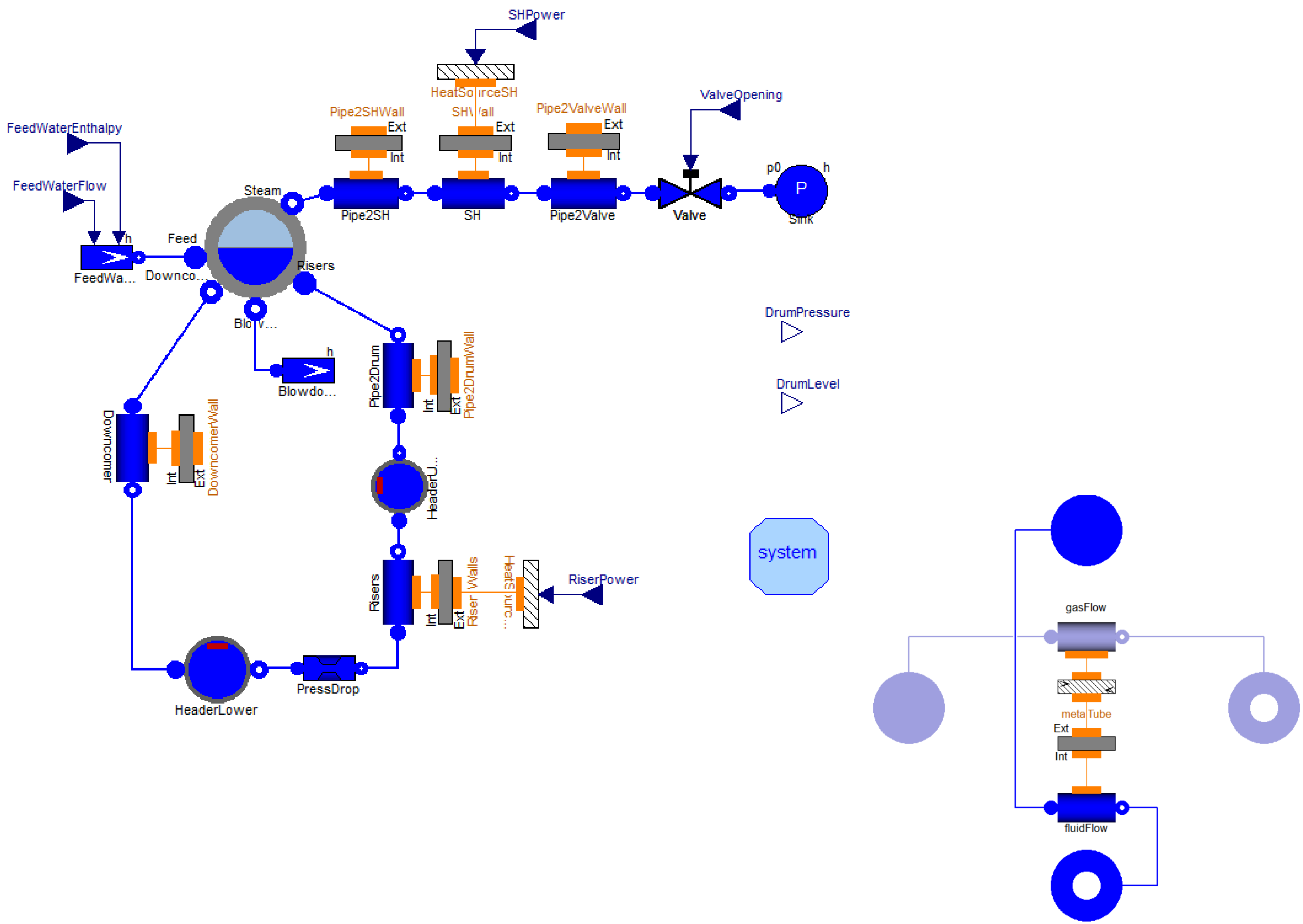
➡ More feedback for the developers

➡ Automatically generated synthetic reports available @ each commit

APPLICATIONS OF OMC TO ENERGY SYSTEM STUDIES @ POLITECNICO DI MILANO

SIMULATION OF BOILERS AND STEAM GENERATORS

Modelling of industrial boilers with Modelica / OMC



Requirements

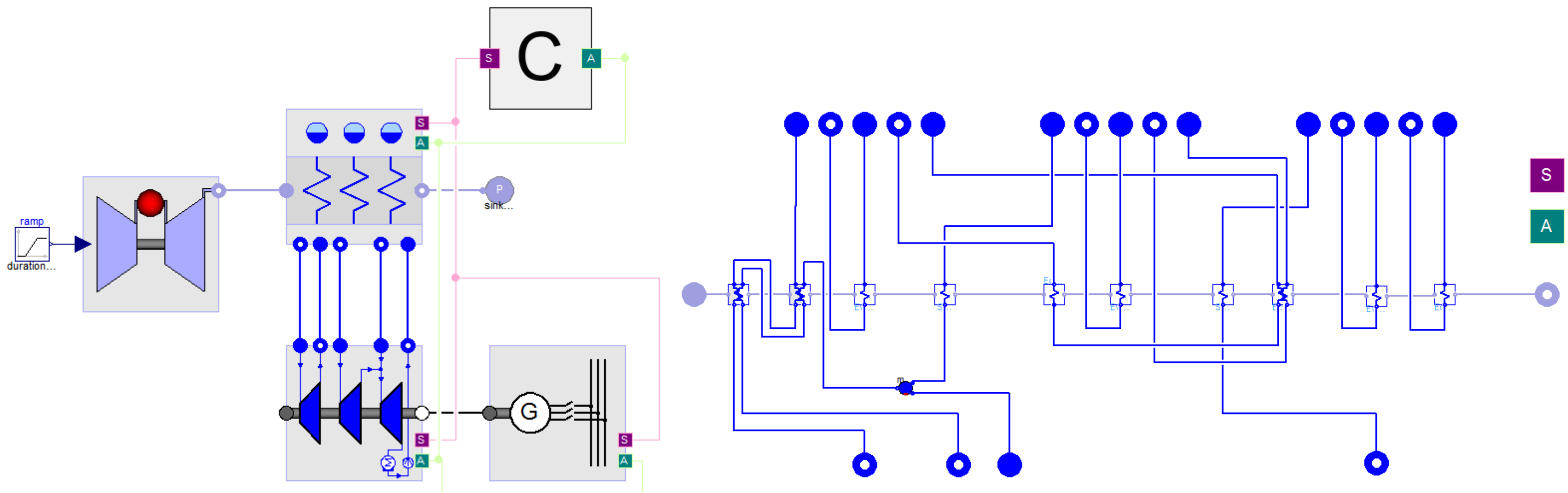
- Use of Modelica for full customization to customer's needs
- Robust & dependable numerical back-end
  - Smooth initialization
  - Efficient and error-free simulation
- Low-cost simulation infrastructure
  - Open source OMC
  - Open source ThermoPower
  - Value-added customer library
- Complete and easy-to-use GUI

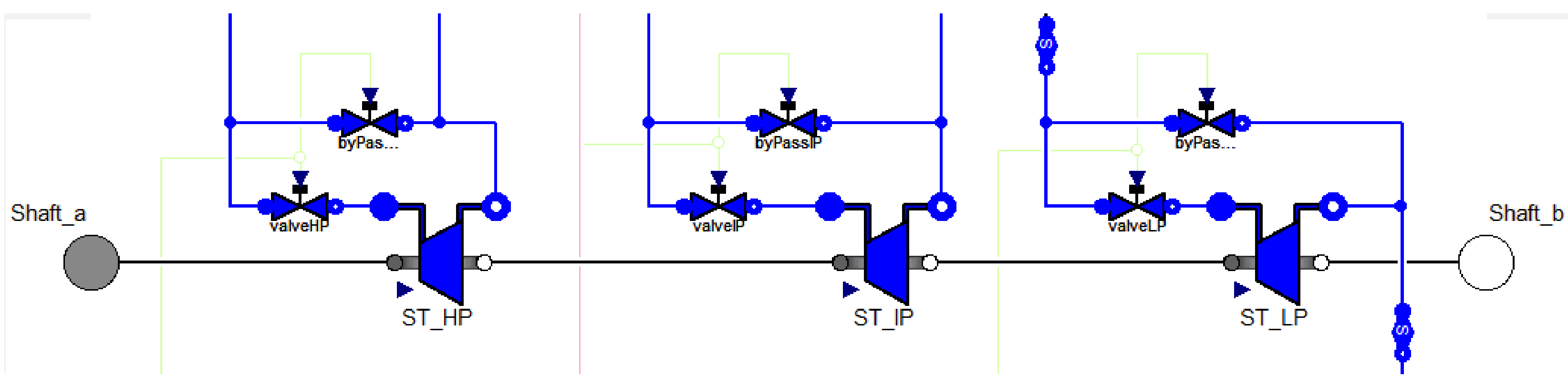
Status

- Two industrial projects (hopefully...) starting Q1 2015
- OMC already viable solution
- Improvements in back-end welcome
    - Full support of homotopy() for initialization
    - More efficient simulation
- Improvements in OMEdit welcome
    - Support of replaceable classes
    - Graphical editing of hierarchical models (nested modifiers)
- Industrial use-cases for OMC testing and advertising

POWER PLANT SIMULATION

Power Plant Simulation





Requirements

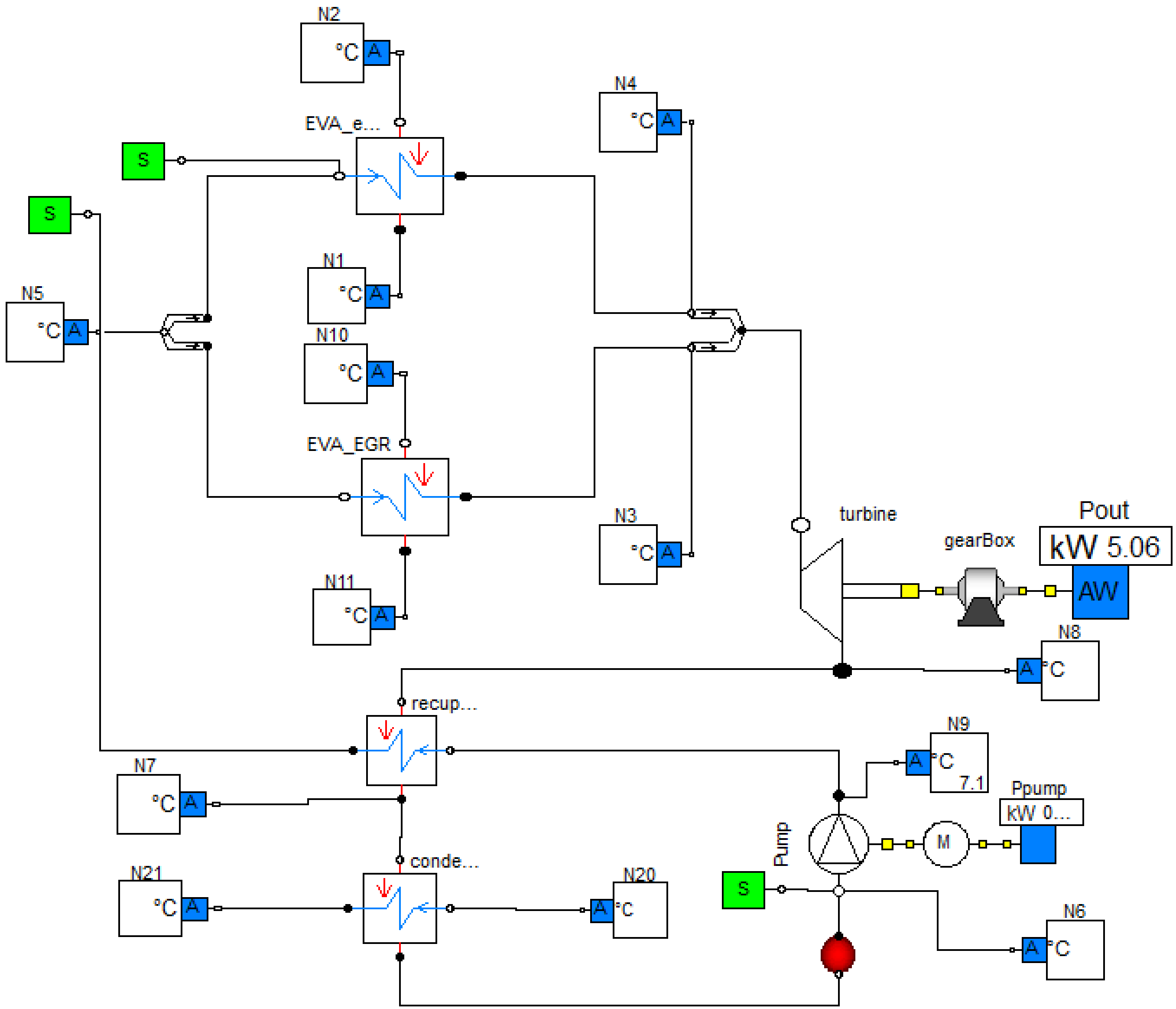
- Efficient handling of large systems (200+ states) with heavy use of IF97 water medium
- Robust initialization: support of homotopy() is strategic
- Open source infrastructure strategic for attracting public funding
- Support of non-conventional media for the study of future concepts
    - Supercritical CO_2 cycles
    - CO_2-capture
    - Integration of thermal storage systems

Status

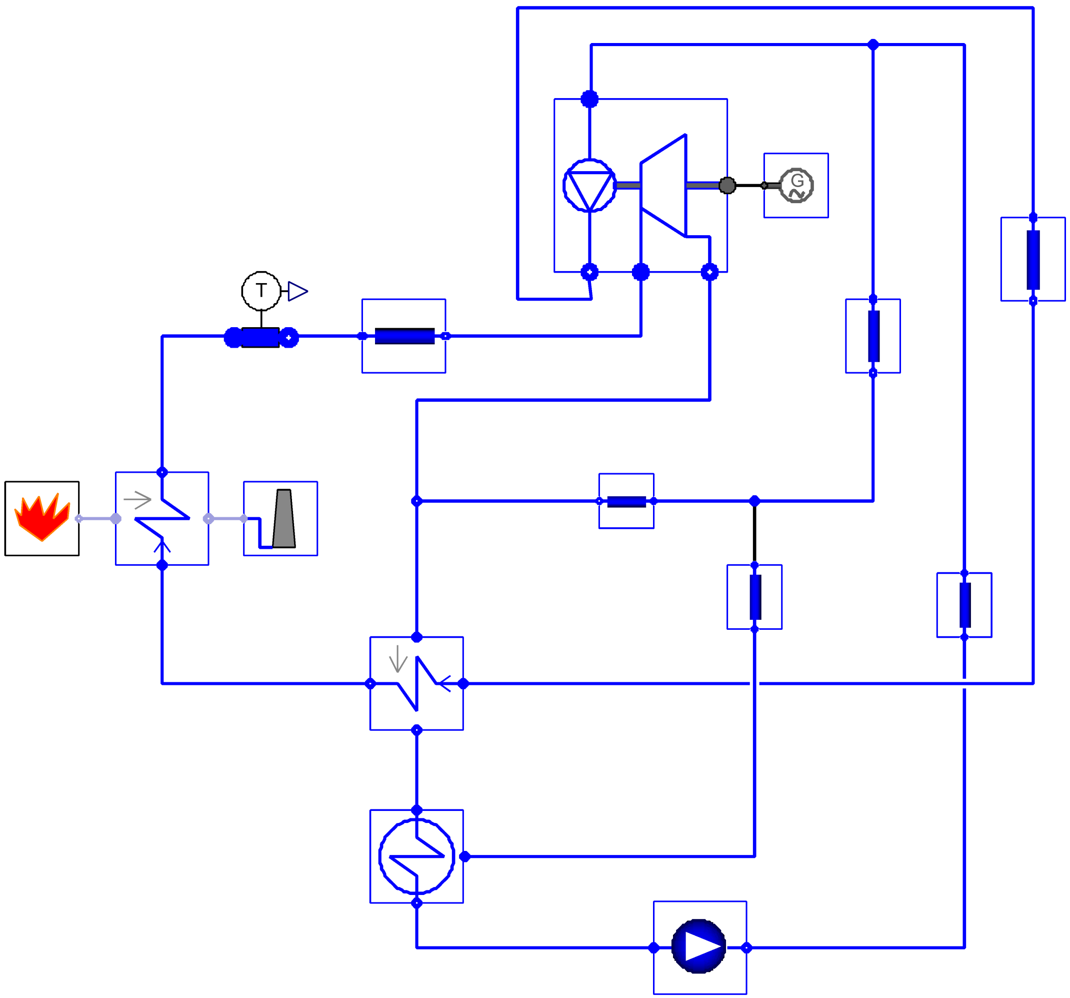
- Currently updating ThermoPower.PowerPlants to run in OMC
- Evaluation and profiling of OMC on full scale models soon possible
- H2020 PowerPlants 2020+ project under review
  - Flexible operation of present and future fossil-fired power plants
  - Coal-fired, combined-cycle, and future CO2 cycle concepts
  - Integration with thermal storage
  - Integrated, open-source modelling and simulation platform based on Modelica and open source tools (→ OMC!)
  - Passed stage 1 evaluation, stage 2 proposal now being prepared

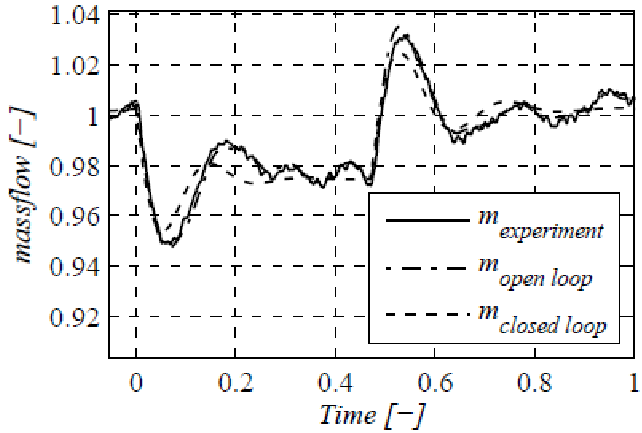
INTEGRATED DESIGN & OPTIMIZATION OF ORC SYSTEMS

Modelica-based cycle and component design

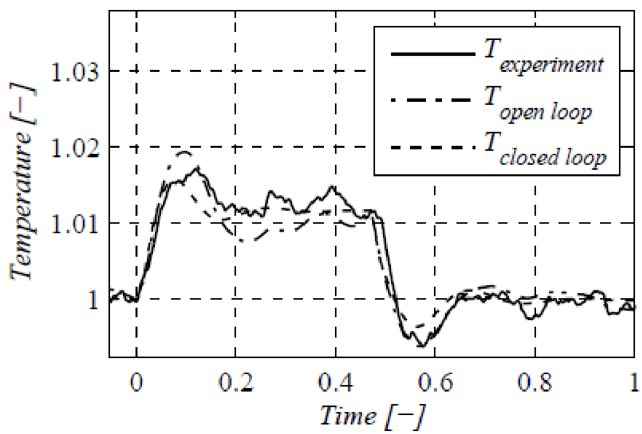


Modelica-based dynamic simulation





(c) Turbine Mass Flow



(e) Turbine Inlet Temperature

Requirements

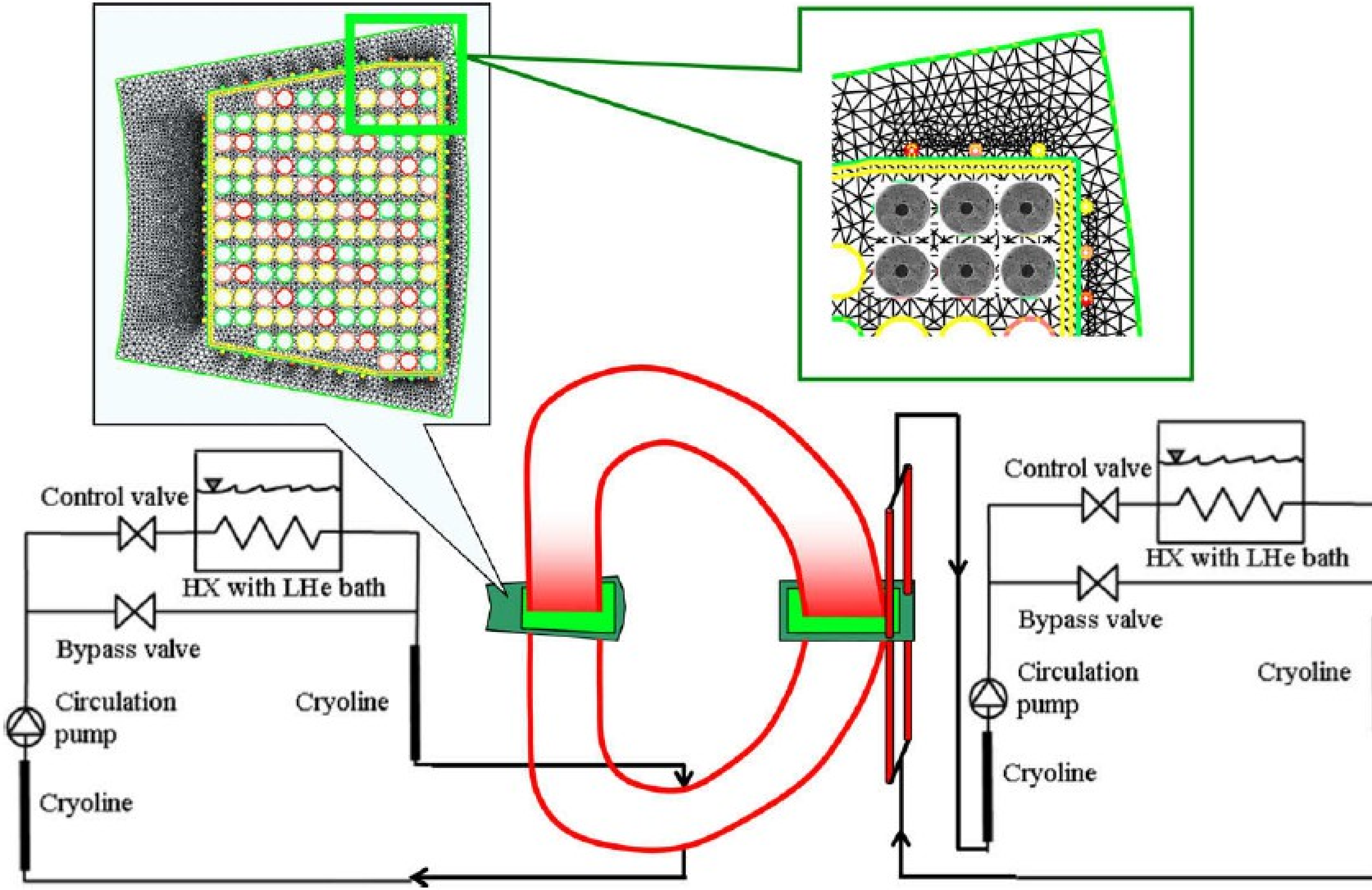
- Equation-based declarative modelling and design rules
- Modelica-based tool for integrated
  - Cycle design
  - Equipment design
  - Dynamic simulation
  - Design optimization (including dynamic behaviour!)
- Open-source infrastructure
  - No royalties, only added value
  - Better framework for public funding
- Very strong nonlinear solver
- Optimization capabilities
  - Derivative-free (via GenOpt)
  - Derivative-based (via Optimica, OMC/Jmodelica?)
- Easy access to exotic organic fluid models

Status

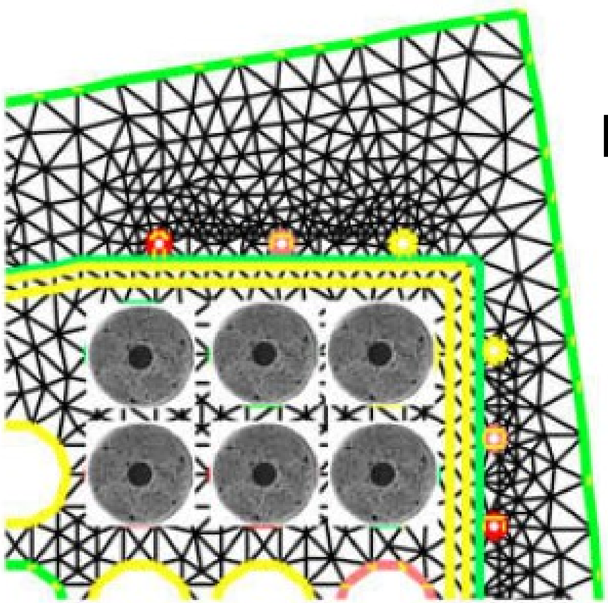
- Dynamic simulation
  - Small library based on ThermoPower available
  - Validated vs. experimental data
  - Works in Dymola
- Equation-based design
  - Prototype currently being developed and tested with Dymola
  - Derivative-free optimization with GenOpt (LLBL, USA)
- Testing with OMC will start next week

SIMULATION OF CRYOGENIC COOLING SYSTEMS FOR SUPERCONDUCTING MAGNETS IN TOKAMAKS

Modelling of SCM cooling systems

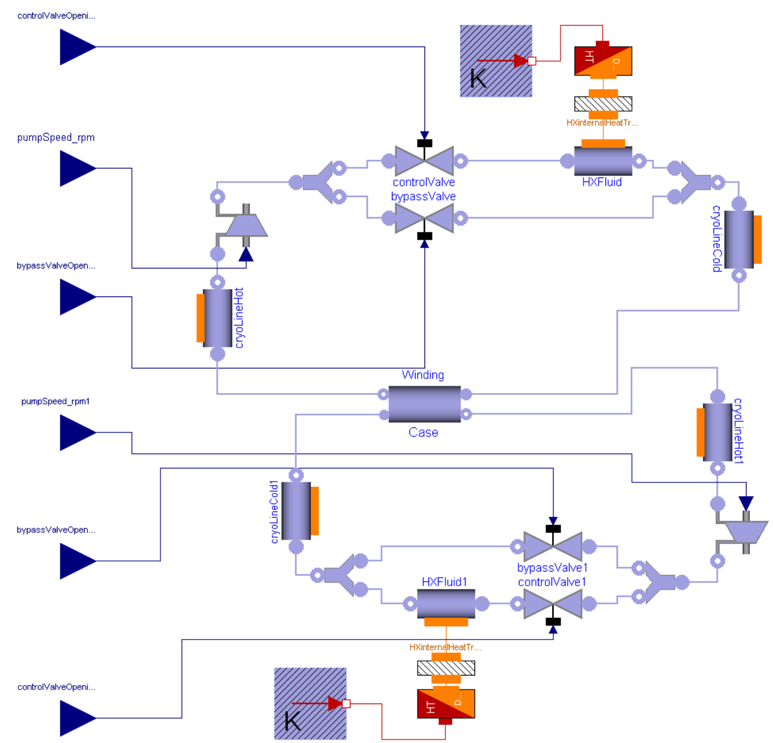


The 4C code



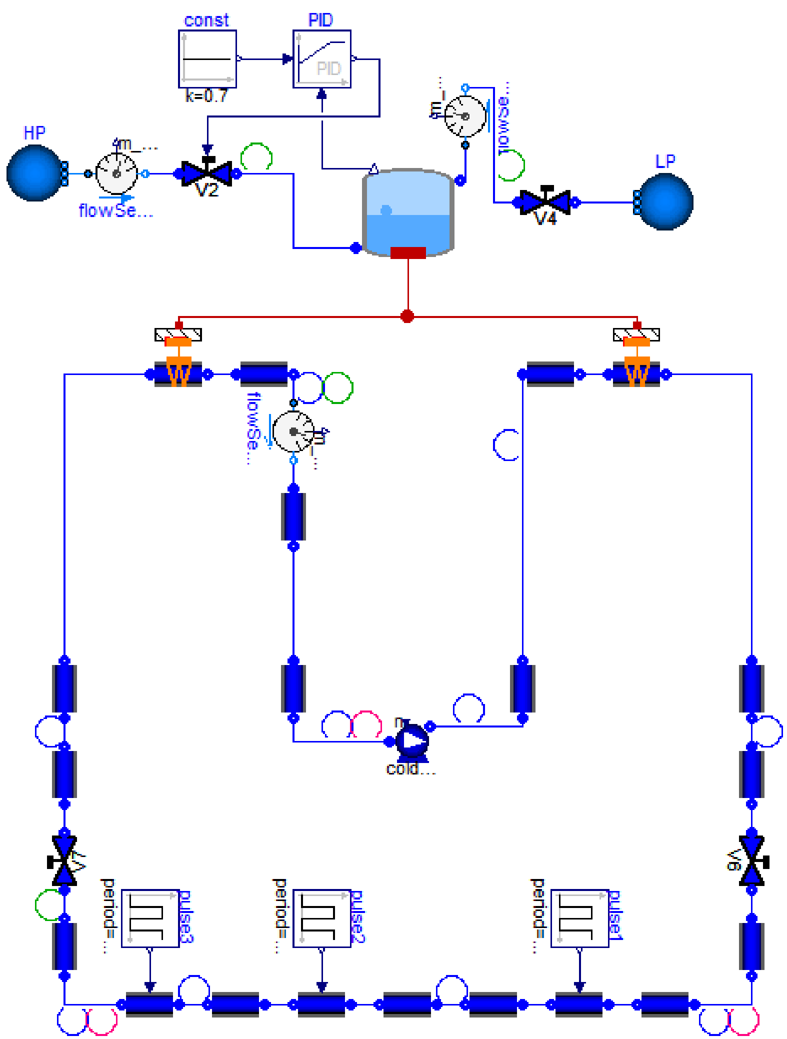
Mithrandir (Fortran code)

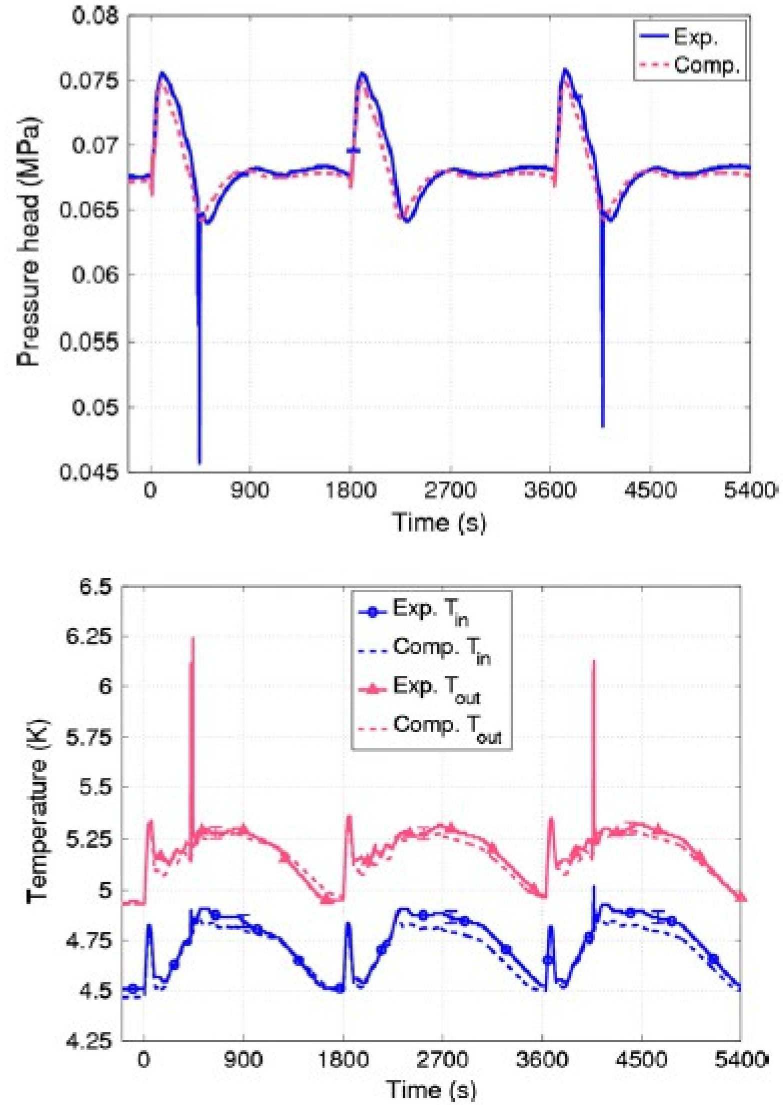
+



Cryogenics (Modelica code)

Validation of Cryogenics on the Helios experiment





Requirements

- Open-source infrastructure
- Closed-source competitors
  - Proprietary high-performance Russian Fortran codes
  - Object-Oriented models for EcoSimPro
- Flexible code generation from same model
  - Stand-alone, variable step-size simulators
  - Fixed-step size simulators for co-simulation
  - Widest choice of implicit integration algorithms
- Robust steady-state initialization of highly nonlinear models
  - Support of homotopy() strategic
- State of the art, Helium models
  - RefProp via FluidProp / ExternalMedia
  - Table-based interpolations of RefProp via CoolProp / ExternalMedia
  - 100% native RefProp implementation via HelmholtzMedia
- Extensible to also handle the cryogenic fluid generation circuit

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- Helium models from HelmholtzMedia library now supported by OMC
- Simple components (pump, valve, helium bath) work fine
- FEM pipe models (from ThermoPower)
  - Back-end issues finally solved one week ago
  - Test results still doesn't match exactly the Dymola results

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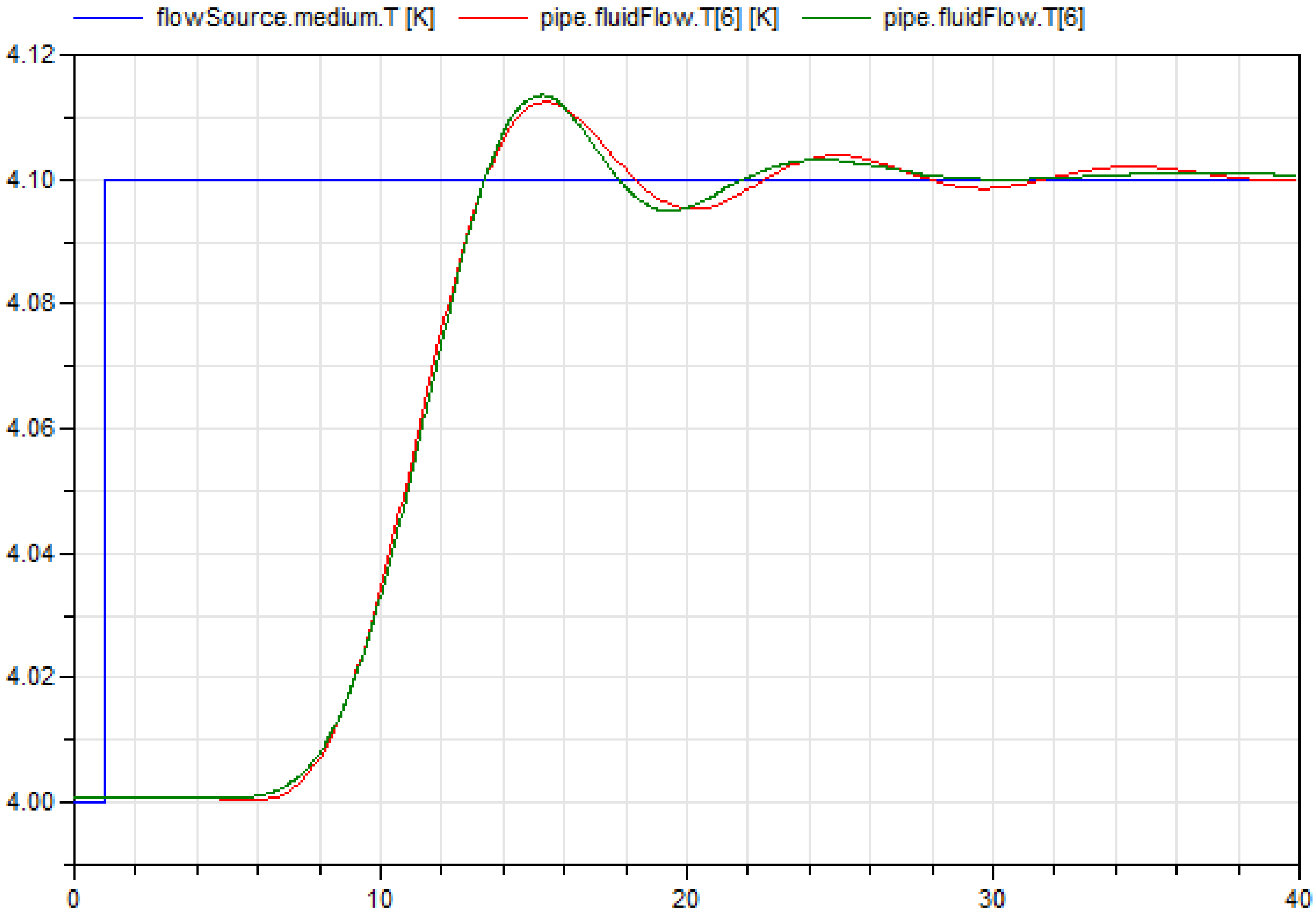

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  - Test results still doesn't match exactly the Dymola results
- Aim at getting 100% coverage by end of February
- Potential Trojan horse to the world of nuclear fusion reactors
  - Full scale studies of cooling systems including cryoplant for ITER
  - Studies of the coupling between Tokamak and steam turbine (DEMO)
  - Access to EURATOM funding

Conclusions and Recommendations

- OpenModelica has vastly improved during 2014
- We can state that models of conventional and innovative energy systems can be handled by OpenModelica
- Feedback from the developers is very effective and very fast
(often better than with commercial sofware)
- The availability of an open-source infrastructure is crucial for both commercial applications and publicly funded research

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- Some key improvements are still necessary for satisfactory performance (and could be carried out within the year 2015)
- Front-end:
  - Avoid losing Media-set start attributes during flattening
  - Fix remaining issues with medium package constants
  - Faster compilation of models using Modelica.Media

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  - Understand and fix issues with the nonlinear solver convergence
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  - Comprehensive Common Subexpression Elimination
- OMEdit (with help from Front-end)
  - Support of replaceable classes
  - Hierarchical editing of models (nested modifiers)
  - Comment- and formatting-preserving parsing and saving

Thank you for your support!

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Thank you for you kind attention!