MODELLING OF HEATING SYSTEMS

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Abstract

Measurement and control of technological processes is important for projecting of buildings and equipments. The quality and effectivity of control systems is rising with help of simulation environments. We have decided to use products of The MathWorks, Matlab/Simulink and Matlab/SimScape for modeling of heating systems. Matlab/SimScape libraries contain special blocks for modeling hydraulic, thermal and mechanical components, which has been used to model this system.

1 Description of modeling environment

Simulink - is a graphical user interface for modeling and simulation of block schematics. The core of the Matlab is used to compute the simulating results. Simulink is primarily used for modeling dynamic systems. Simulink's libraries offer a plenty of blocks useful for modeling complex systems. With help of integrating methods, we can simulate the system and analyze it in time.

Simscape – is a library of basic real world mechanics, hydraulics and electronics components. System, built from these blocks, is modeled from view of energy flow. Model works directly with physical parameters, so it approximates good real systems. Simscape generates differential equations from the modeled system that can communicate with other components from Matlab/Simulink after the simulation has been started.

SimHydraulics – is a tool for modeling and simulation of hydraulic systems. It allows modeling of multi-domain systems, which contain connection of hydraulic and mechanical components.

2 Block description

Model of heating system was built-up according to project of real heating system. Modeling of three-way mixing valve was ignored, because its main task is anti-corrosive protection.

2.1 Pump model

For modeling of pump, we've chosen *fixed-displacement pump* model, from Simscape/ SimHydraulics/Pumps and Motors library. This block, shown in fig.1, represents model of pump with fixed displacement. Model has two hydraulic ports (input T and output P) and one mechanic port (input S).
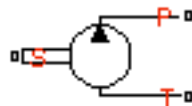

Figure 1: Fixed- displacement pump model

Fixed-displacement pump is described by following equations:

$$q = D * \omega - k_{leak} * p \tag{1}$$

$$T = D * p / \eta_{mech} \tag{2}$$

$$k_{leak} = k_{HP} / v * \rho \tag{3}$$

$$k_{HP} = \frac{D * \omega_{nom}(1 - \eta_V) * v_{nom} * \rho}{p_{nom}} \qquad (4)$$

$$p = p_T - p_P \qquad (5)$$

, where:

q	– Pump delivery
p	– Pressure differential across the pump
p_t, p_p	- Gauge pressures at the block terminals
T	– Torque at the pump driving shaft
D	– Pump displacement
Ω	– Pump angular velocity
k_{leak}	- Leakage coefficient
k_{HP}	- Hagen-Poiseuille coefficient
η_V	- Pump volumetric efficiency
η_{mech}	– Pump mechanical efficiency
v	- Fluid kinematic viscosity
ρ	- Fluid density
p_{nom}	- Pump nominal pressure
ω_{nom}	- Pump nominal angular velocity
v_{nom}	- Nominal fluid kinematic viscosity

2.2 Shell and tube heat exchanger model

The model implements shell and tube heat exchanger. Primary medium, which contains combustion gas, flow out from boiler to heat water in pipes. Model consists of two parts; hydraulic part and heating part. Hydraulic part is modeled by pipes, blocks from SimHydraulics library. Heating part is modeled by differential equations:

$$\rho_2 c_{p2} \frac{V_2}{n} \frac{dT_{2n}}{dt} = M_2 c_{p2}\left(T_{2(n-1)} - T_{2n}\right) + \lambda_{12} \frac{S}{n}\left(T_1 - T_{2n}\right) \qquad (6)$$

$$\rho_1 c_{p1} V_1 \frac{dT_1}{dt} = M_1 c_{p1}\left(T_{10} - T_1\right) - \sum_{j=1}^{n} \lambda_{12} \frac{S}{n}\left(T_1 - T_{2j}\right) \qquad (7)$$

The pipe is divided into 5 parts in heating part of model. Heating losses, boiler dynamics, reheater dynamics and dependency on parameters (density, specific heat) from temperature were not modeled. PI controller controls output temperature by changing flow of primary medium. The model of shell and tube heat exchanger is shown in fig. 2. Simulation results of temperatures from experiment of starting the exchanger are shown in fig. 3.
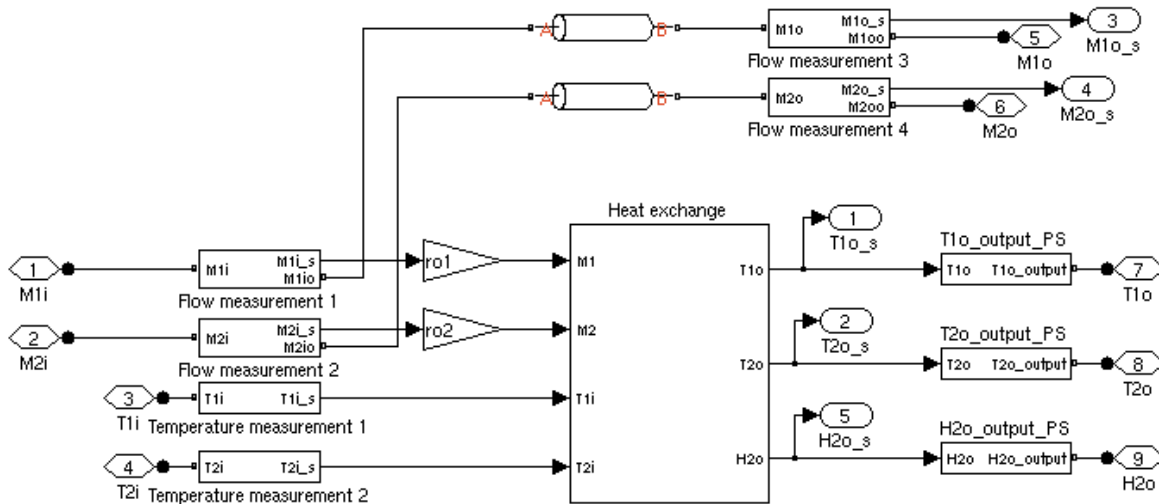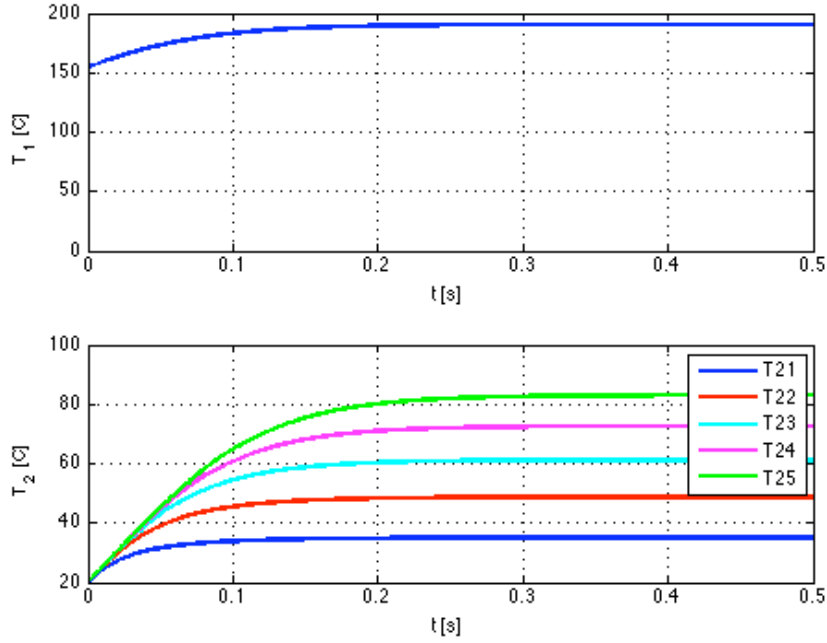

Figure 2: Shell and tube heat exchanger model

Figure 3: Experiment results from starting of the shell and tube heat exchanger model

2.3 Consumption modeling

The model, shown in fig. 4, represents consumption heating system in residential building. The model consists of ascending pipes model and models of residential apartments. The model of residential apartment is realized by indirect heat exchanger with centralized parameters and heat losses to ambient. Each residential apartment is modeled by one heat exchanger. The residential building model consists of 10 levels, where on each level should be found 4 apartment models. Residential apartment is modeled by equations (8) and (9).

$$\rho_1 c_{p1} V_1 \frac{dT_1}{dt} = \rho_1 c_{p1} T_{1i} Q_{1in} - \rho_1 c_{p1} T_1 Q_{1out} - \lambda_{12} S_1 (T_1 - T_2) \qquad (8)$$

$$\rho_2 c_{p2} V_2 \frac{dT_2}{dt} = \lambda_{12} S_1 (T_1 - T_2) - \lambda_{23} S_2 (T_2 - T_{ok}) \qquad (9)$$

, where:

ρ_1 - Density of primary medium

c_{p1} - Specific heat of primary medium

V_1 - Primary medium capacity

T_1 - Temperature of primary medium

ρ_2 - Density of secondary medium

c_{p2} - Specific heat of secondary medium

V_2 - Secondary medium capacity

T_2 - Temperature of secondary medium

T_{ok} - Temperature of ambient

λ_{12} - Heat transfer coefficient between primary and secondary heat capacity

S_1 - Heat transfer surface between primary and secondary heat capacity

λ_{23} - Heat transfer coefficient between secondary heat capacity and ambient

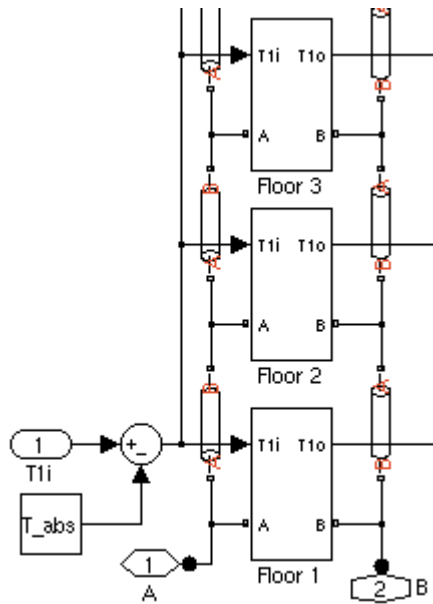S_2 - Heat transfer surface between secondary heat capacity and ambient

Figure 4: Model of heating consumption

2.4 Modeling of heating system

This model represents heating system for residential building with primary and secondary circuit of fumigation. Source of heat is represented by shell and tube heat exchanger. Water is pumped from here through displacement pump to pipes of primary circuit and then through distributer and ascending pipes to end consumption. The consumption is modeled like heat exchanger, while heat losses to ambient are respected. The water flow then through ascending pipes and pipes back into the shell and tube heat exchanger. Whole system model is shown in fig. 5.
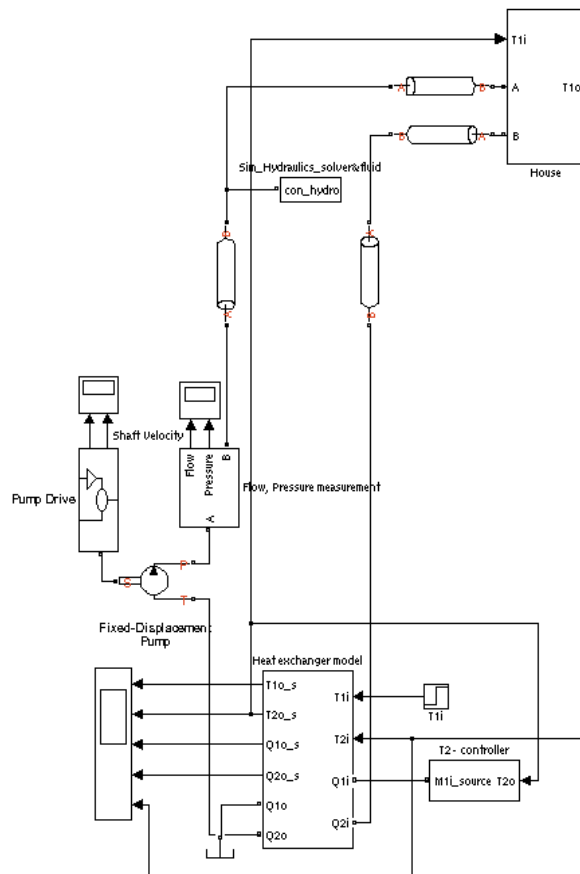

Figure 5: Heating system model

3 Experiment setup and simulation results

Experiment consists of step change of desired value of secondary medium output temperature of shell and tube heat exchanger in 1800 s from 80 °C to 90 °C. Then a disturbance has been modeled: decrease of motor speed, which drives the fixed displacement pump, by 20 % in 7200 s. The disturbance has effect of decreased flow of water and implicitly decrease of hot water delivery to consumption place. Simulation results from this experiment are shown in fig.6 and fig. 7.
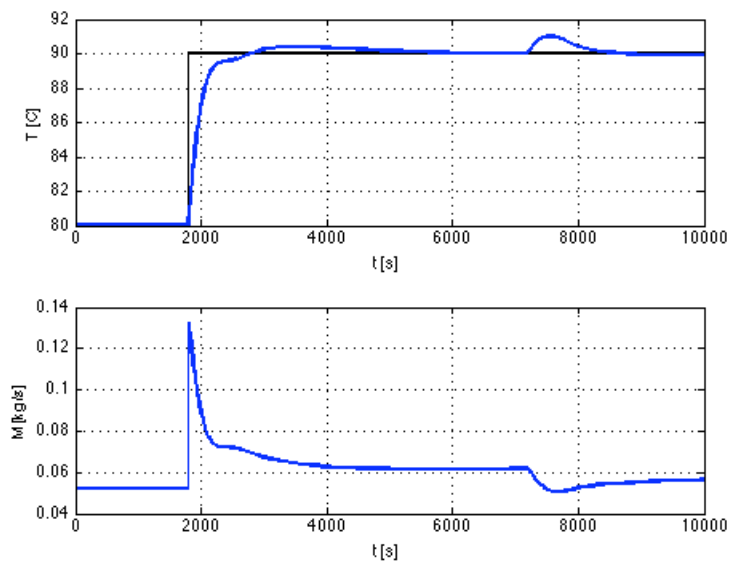

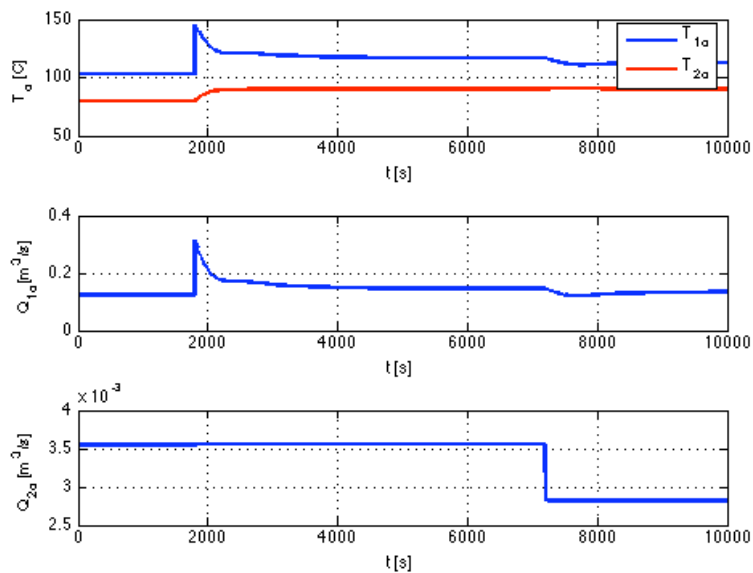Figure 6: Secondary medium temperature of shell and tube heat exchanger and flow of combustion gas

Figure 7: Output temperatures and flows of shell and tube heat exchanger

4 Conclusions and results

The model describes heating system dynamics and consists of shell and tube heat exchanger, temperature control of secondary medium, fixed displacement pump, pipes, ascending pipes and end consumption. It is possible to setup many experiments (simulation of disturbances, new control units) for studying dynamics of hydraulic and heat systems on the model. Hydraulic part of system is modeled using Matlab/SimHydraulics environment, which is mainly used for modeling of heavy hydraulic machines, applications from aviation department, defense department and industry. From

experiment results mentioned in this article, we can demonstrate that Matlab/SimHydraulics should be used for modeling and simulation of heating systems.

Acknowledgement

References

[1] O. LULKOVICOVÁ, D. PETRÁŠ, V. KABÁT, *Zdroje tepla a domové kotolne*, Jaga Group, 2004. 200 s. ISBN 8080760012.
[2] J. KUNEŠ, *Modelování tepelných procesú*, Praha 1989, STNL, 423 s., ISBN 80-03- 00134-X
[3] J. CERMÁK, V. PETERKA, J. ZÁVORKA, *Dynamika regulovaných soustav v tepelné energetice a chemii*, Praha 1968, ACADEMIA, 580 s.
[4] D.PETRÁŠ, D. KALÚS, D. KOUDELKOVÁ, *Vykurovacie sústavy STU Bratislave*, 2002. 296s., ISBN 80-227-1643-X
[5] R. PETITJEAN, *Total Hydronic Balancing. Edition Tour & Anderson Hydronic*, 1997
[6] J. Pekar, P. Trnka, V. Havlena, *MATLAB AS A PROTOTYPING TOOL FOR HYDRONIC NETWORKS BALANCING*, 2008
[7] The MathWorks, *Getting started with Matlab, version 7.7*, 2008
[8] The MathWorks, *Getting started with Simulink, version 7.2*, 2008
[9] The MathWorks, *SimHydraulics User's Guide, version 1.4*, 2008
[10] A. Pavlúsová, *Modelovanie tepelných systémov – SimHydraulics,* cit. 24.10.2009, available at: http://www.posterus.sk/?p=266

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