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ON DECLARATIVE PROCESS MODELLING AND REPRESENTATION BASED ON PHYSICAL PROCESS DECOMPOSITION

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Abstract: The work is looking to declarative process modelling and representation based on physical decomposition of the process. The Modelica language is used for study. The approach is based on reality that a process model, which declaratively describes the phenomena and uses the physical structure of the plant, is much easy to understand, to reuse and to develop it in a concurrent and more efficient way. A simple case study based on coupled tanks is considered and discussed. The approach can be used for simulation and design of start-up and shut-down operations in real and complex industrial plants.

Keywords: Process modelling, Physical decomposition, Methodology, Declarative modelling.

1. INTRODUCTION

In process modelling field, the physical orientation in modelling is not a new feature. The decomposition of the physical plant and processes into individual objects is a powerful technique to manage complexity. The generic example is the effort under Modelica modelling language development, [1]. It is used in some modelling and representations languages, e.g., [2], and it is the subject of intensive research efforts as described in [3], [4], [5], or [6].

Engineering system models are preferably developed graphically. As a matter of fact, graphical editors have largely replaced textual simulation languages. Hence, the question might arise what is the relevance of a (standardized) textual model description language. Some answers to the question might be:

1. a textual language may well serve as a uniform intermediate format for several graphical formalisms;
2. the need to have a neutral exchange format between proprietary modeling and simulation tools.

The paper's goal is to present the advantages of the process models based on object-based technology and physical oriented, in balance with equations based models. A very simple process is considered composed from three connected vessels (tanks). The approach is useful at least from two reasons: it offers o more natural way to think and to construct models, looking on physical structure of the process; it is one way to represent models in order to exchange models and to construct ware-houses of models.

The considered phenomena are related to the pressure and flow of the fluid from one thank to another one, i.e, the flow and the accumulation of fluids. The un-considered phenomena are inertia and friction. As a general strategy, a correlation among considered and un-considered phenomena must be considered here, which can be made, e.g., by symbolic computation and a correlation matrix, in the sense that phenomena from different domains and levels are connected and by cancelling one of them the correlated phenomena must be cancelled also.

The declaration of the modelled phenomena is made in a very simple way by "declaring" what phenomena are considered. It seams to be important here to have ontology related to phenomena and agents of the modelling environment must assist the management of such declarations.

In the next section the process is presented and some basic equations concerning the considered phenomena are presented. The Modelica code for sub-models is presented in section three. In section four some simulation results and – finally – the conclusion are presented.

2. THE PROCESS DESCRIPTION

The process consists on three tanks connected by long pipes and valves near the vessels, as was presented in Fig. 1 where the valves were considered together with electrical drives, which was not represented in the figure. The scope of the model is to explore the behaviour of the process under different initial condition. For this case the following assumption were considered: (i) one phase material: liquid; (ii) one component: water; (iii) isothermal process: environment temperature; (iv) no reactions. The process model is obtained by concatenation of three sub-models: tank, pipe and valve. For each one constitutive equations were considered in order to obtain the right behavior. Some of them will be presented in the following.

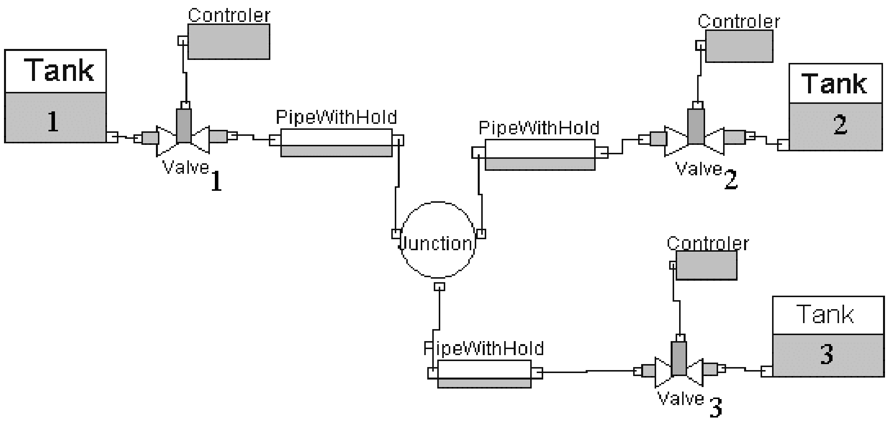

Figure 1: The process under study

2.1 The valve equations

The valve has a flow resistance, for which reason it is introducing a model based on equation

$$\frac{dV}{dt} = C_V \cdot f(x) \cdot \sqrt{\frac{dp}{s.g}} \qquad (1)$$

where *dV/dt* is the volumetric flowrate; C_v is the valve coefficient; *x* is the fraction of valve opening; *dp* is the pressure drop across the valve; s.g. is the specific gravity of the fluid; *f(x)* is the flow characteristic, which varies from 0 to 1, as a function of *x*. For a quick-opening valve $f(x)=\sqrt{x}$, i.e., the sensitivity of flow to valve position (fraction open) is high at low openings and low at high openings.

2.2. The pipe equation model

The fluid resistance, *R*, relates efforts to flows in the considered two port model

$$dp = p_1 - p_2 = q \cdot R \tag{2}$$

where *q* is the volume flow rate and *dp* is the difference pressure. The fluid flow is assumed to be laminar and the resistance is computed by

$$R = \frac{128\mu l}{\pi d^4} \tag{3}$$

where μ is the viscosity in [N.s/m^2], *l* is the length in [m], *d* is the inside diameter in [m].

2.3 The tank equations

If the container is neither heated nor cooled, the mass will be the only conserved quantity to be considered and the mass density is constant if the liquid enters and leaves at the same temperature. The tank model will have only the mass balance equation. The gravity is considered important in this case.

3. THE MODELICA PROCESS MODEL

Before defining the models under Modelica, interfaces (ports or connectors) should be defined. A port is a place where matter is coming in or is going out from the considered volume of space. A fluid port is any place in a hydraulic circuit where an average pressure and volume flow rate can be defined. The Modelica code is then

```
connector PortFluid
  flow volflowrate q;
  pressure p;
end PortFluid;
```

3.1 The pipe model

The following phenomena are modelled: (1). accumulation of the matter (liquid) in pipes, very important in start-up and shut-down operations; (2) resistance of pipe at fluid dynamics.

The fluid accumulation in long pipes is modelled by a hold-up. The flow at one end of the pipe must fill-up the hold-up volume. After that, the flow is arriving at the opposite end of the pipe. This simple declaration of the behaviour corresponds to reality where a delay of the flow in pipes is observed.

The considered model is presented in Fig.2. as a combination of a hold-up element connected with two static pipes, i.e. without accumulation. The static pipe model generates the "hydraulic" resistance of the pipe. The "T" connection is necessary in order to avoid simulations incompatibility. A simple explanation is that the volume in the hold-up is a state variable and must be "independent" of the connections. If the hold-up volume is considered on the left or on the right side then - when connecting with tanks, for example - two state variables are "connected" in parallel. In this case it follow that the tank and the connected pipe may have the same dynamics, which is not true.

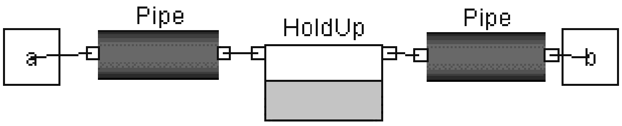

Figure 2: The model of the pipe with accumulation

The Modelica code for pipe can be as

```
model Pipe "Pipe with pressure effects and fluid delay"
      PortFluid a,b;
      HoldUp hold;
      StaticPipe staticcpipe1, staticcpipe2;
equation
      connect(a, staticpipe1.a);
      connect(staticpipe1.b, hold.a);
      connect(hold.b, staticpipe2.a);
      connect(staticpipe2.b, b);
end Pipe;
```

3.2 The Tank model

The Modelica code for the tank is presented below. As an alternative, in order to consider open vessels and the interaction with the environment, the tank model will be considered as models with two ports, one connected to environment model.

```
model Tank "A tank with fluid"
    extends FluidProperties;
    extends TankGeometry;
    extends Environment;
    Volume fluidvol(start=100, min=0, max=tankvol);
    PortFluid a;
equation
    der(fluidvol) = a.q;
a.p = envpress + (fluidvol*rho*gravity/tankarea)*convpress;
end Tank;
```

3.3 The valve model

Instead of considering a set complex of equations to exactly generate the behaviour of the process, ideal static and dynamic characteristics are used many times. If the detailed switching behaviour of the valves is neglectable with regards to other modeling effects, it is often sufficient to use the ideal valve characteristic, which typically gives a simulation speedup of 1 to 2 orders of magnitudes. To avoid some problems on simulation stage the parameterised form of the switching characteristique was used, i.e., by introducing for volum flow rate and pressure some relations like $v=v(s)$, $p=p(s)$, with s as curve parameter. This description is more general and allows the user to describe discontinuities *uniquely* in a *declarative* way. The technique of parameterised curve descriptions was introduced in [8] and used in some modelling languages, e.g., [9].

```
model Valve "A model for valve"
        PortFluid a,b;
        PortControl c;
        Pressure dp;
        Boolean on;
        Real s;
equation
        on = c.u > 0.5;
        a.q + b.q = 0;
        dp = a.p - b.p;
        dp = if on then 0 else s;
        a.q = if on then s else 0;
end Valve;
```

3.4 The process model

The process model is a declaration of used models, i.e., tanks, pipe, valves and junction, and of the connecting topology:

```
model Tanks "Communicative vessels with valves"
        Tank tank1, tank2, tank3;
        Pipe pipe1, pipe2, pipe3;
        Valve valve1, valve2, valve3;
        Controler ctrl1, ctrl2, ctrl3;
        Junction3P junction;
equation
        connect(tank1.a, valve1.a);
        connect(valve1.b, pipe1.a);
        connect(pipe1.b, junction.a);
        connect(junction.b, pipe2.a);
        connect(pipe2.b, valve2.a);
        connect(valve2.b, tank2.a);
        connect(junction.c, pipe3.a);
        connect(pipe3.b, valve3.a);
        connect(valve3.b, tank3.a);
        connect(ctrl1.c, valve1.c);
        connect(ctrl2.c, valve2.c);
        connect(ctrl3.c, valve3.c);
end Tanks;
```

4. SIMULATION RESULTS

Two simulation results are presented in Fig. 3., which reflect the real behaviour of the process. The pipes are with accumulation, and, finally, the vessels will have the same fluid height.

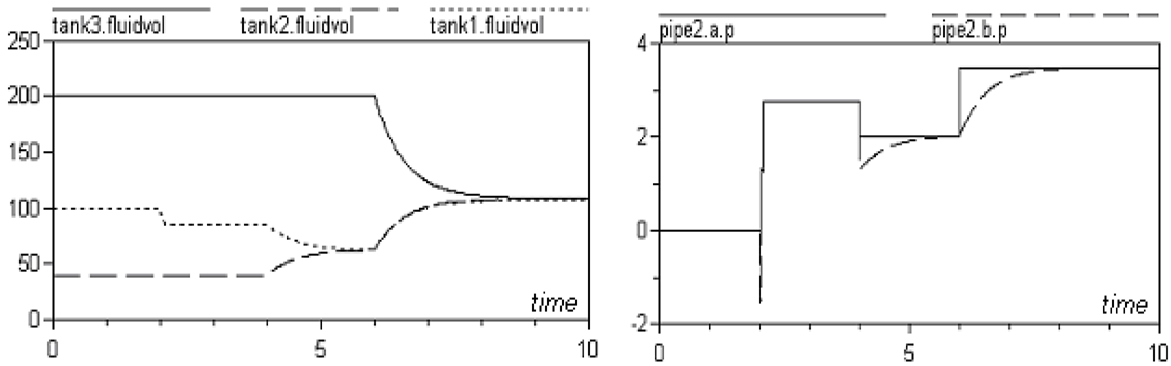

Figure 3: Time evolution of the volume fluids and pressures in tanks:
Control scenario: *ctrl_1* = 2s, *ctrl_2* = 4s, and *ctrl_3* = 6s.

5. CONCLUSIONS

The scope of the was to present a process-modelling framework based on physical decomposition of the process under study and looking to the phenomena running in the process. The models are obtained in a declarative way, which allows a standard representation of the knowledge about the considered process and an easy way to understand the behaviour of the process under different modelling hypothesis and different simulation scenario. Finally the right behaviour, under the considered hypothesis, is obtained by presenting some of the simulation results.

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