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ON PHENOMENA BASED MODELS OF CONTINUOUS CASTING PROCESS

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Abstract: The paper is looking to continuous casting process models based on phenomena with Modelica modelling and representation language. The models are based on thermal and transport phenomena. The obtained declarative models are used in a multi-level control strategy as information generators of qualitative behaviour of the real process.

Keywords: Casting Process Modelling, Object-oriented modelling, Phenomena based modelling, Modelling, Declarative Models.

1. INTRODUCTION

Continuous casting process modelling of materials is difficult, mainly of the complexity of the process with phase transformation of base material and multiple phase transformation (liquid-vapour) of many other auxiliary materials. The process has multi-domain interactions: material science, electrical drives, mechanics, physics, and chemistry. In addition there are constant materials, transport and thermodynamic quantities, which are difficult to estimate even for experts in materials science and with powerful software tools and machines. The references from [1] to [5] are some examples in the description of the process and of the problems generated in the process modelling and simulation.

From the point of view of macro-scale and for simulation purposes it is much better, at least in the first framework, to use simple and macro-scale phenomena, based on the energy transfer, in the description of the behaviour of the process. The paper approach is based on this idea and a phenomena based model is developed in order to obtain qualitative information about the continuous casting process. The advantage of such solution is in the easiness of understandability of the model and sub-models. The presented model is partial; decomposition of models in sub-models is still under way. The qualitative model is used to generate information in a multi-level control strategy where the temperature of the materials is an important input to decision and control system. In section 2 the structure of the model is presented with the description of the necessary models and interfaces. In section 3 the main models are presented and discussed, i.e., the model of the ladle, the model of the tundish, and the cooling model. The section 4 presents some simulation results in order to understand better the features of the model.

2. THE STRUCTURE OF THE MODEL

From the methodology point of view a metamodel is presented in Fig.1. The process model in considered to be an aggregation of one physical model, one or more material models and one or more phenomena models. Material and phenomena models needs properties models to compute the thermodynamic and transport properties. The physical model in association with the properties model generates constraints related to the behaviour of the model. All considered sub-models can be developed independently in a concurent engineering strategy, and possible in distributed sites.

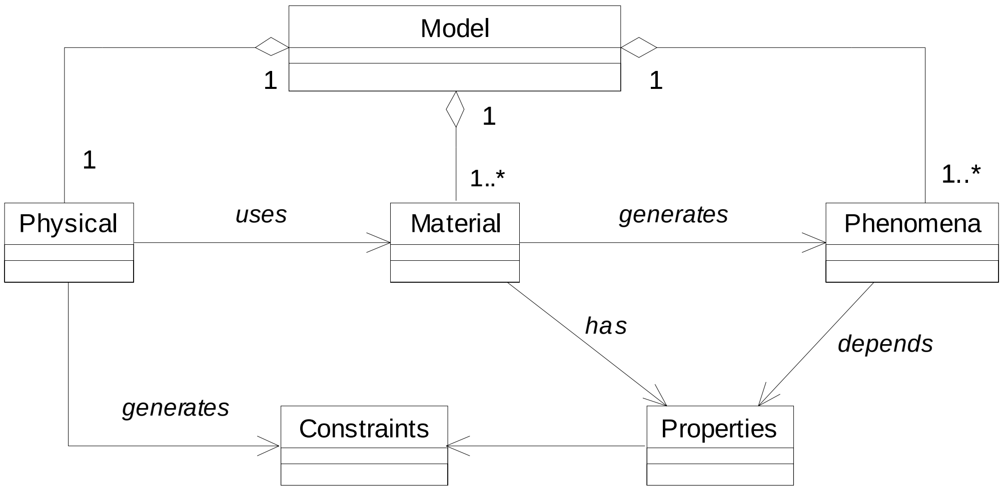

Figure 1 : A *partial* metamodel of the process model

In correlation with the presented hypothesis the following phenomena from two domains were considered as it is presented in Fig.2: thermal and fluid phenomena. In the thermal domain the considered phenomena are: conduction and radiation. From the fluid domain, fluid flow is considered as effect of difference pressure.

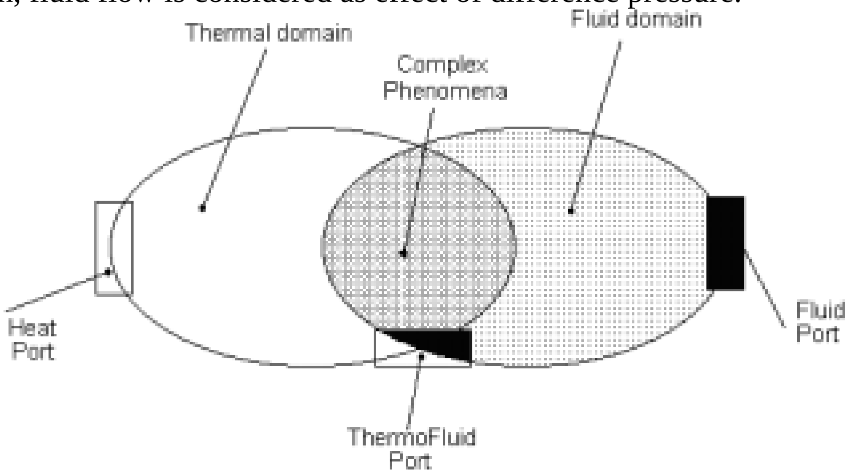

Figure 2: Interfaces among different domains of phenomena

The following information is necessary for the considered phenomena: temperature and heat flow rate for thermal domain; pressure, temperature and volume flow rate for fluid domain. The thermo-fluid material interfaces can be as

```
connector PortThermoFluid
    Pressure p;
    CelsiusTemperature T;
    flow VolFlowRate qvol;
end PortThermoFluid;
```

The name flow shows that the considered variable are transport quatities, e.g., volume flow rate and heat flow rate. Any other variables, without the prefix flow, e.g., temperature or pressure, are conservative quantities.

The basic equations for process sub-models are related to mass balance and energy equations. In addition of those, constituitive equations should be considered to obtain the right behaviour of the model.

3. THE PROCES MODEL

The ladle is modelled by two material sub-models: the steel and the wall model. The input variable in the ladle is the initial temperature T_0. The necessary phenomena are related to the time variation of temperature inside and outside of the ladle and the variation of the steel inside of the ladle, as effect of some control inputs. It is supposed that the steel is in liquid phase and no phase change is performed in the ladle.

The transfer of thermal energy from ladle to outside of ladle is modelled by radiation phenomenon, from the surface of the ladle to environment. The environment model is necessary to show the influence of the high temperature source, as the liquid steel is, to air medium around the ladle. It is expected that the temperature environment to rise in time with or without change on the steel volume inside of the ladle. The energy transfer from liquid material to environment is modelled by conduction phenomenon. The two thermal phenomena are described below under Modelica language.

```
model Conduction
  PortHeat ha,hb;
 ThermalConductivity thermalcond;
 Thickness thick (start = 1);
 Area transfer_area (start=1);
 Real Rth(start=1, min=1E-6)
 “Resistance";
algorithm
   Rth := thick / thermalcond /
transfer_area;
   ha.qheat := (ha.T - hb.T) / Rth;
equation
   ha.qheat + hb.qheat = 0;
// un-defined: thick, thermalcond,
transfer_area;
end Conduction;
```

```
model Radiation
  PortHeat ha,hb;
  constant Real viewfactor = 0.1;
  constant Real sigma(final
unit="W/(m2.K4)")=5.6704e-8";
 Area transfer_area (start=1, min=0);
 Real Rth(start=1, min=1E-6);
algorithm
  Rth := 1 / sigma / transfer_area /
  viewfactor;
  ha.qheat := (ha.T^4 - hb.T^4) / Rth;
equation
    ha.qheat + hb.qheat =0;
// un-defined: transfer_area;
end Radiation;
```

The wall model is composed mainly from a physical model, which defines the size and the composition of the wall, and the steel model.

The input variable in the tundish model is the volume flow and the steel height inside of the tundish is the controlled variable. The base phenomena are related to the flow of materials from ladle to tundish. Because no phase transformations are performed here, for the material model is necessary to have only a model for the liquid phase. The interaction with the environment is made only by the lateral surface of the tundish. The structure of the ladle and of the tundish is the same. Both use a material model (steel) and a wall model. The wall sustaines the stell. The model for the processed material is called Steel. It has two thermofluid ports and one heat port. The first two are necessary to model the flow of the steel. The heat port is necessary to model the intercation with the wall. The right (qualitative) behaviour can be obtained with or without inheritance features. The models without inheritance are more compact and easy to modify. The reverse side is that such models are more complex then models with inheritance capability.

The phenomena, which describe the cooling model, are based on energy transfer from cold water to liquid steel via a separation material, in the primary stage, or by direct contact in the secondary stage. The real process, even with modern and multi-level control strategies, recommends such an approach also where only global variables are used. The difficulty of the modelling is on estimation of the variable thermal resistances to obtain right quantitative results. Related to this difficulty, in some research department, e.g. [5], the estimation of such parameters is studied as an inverse problem.

The partial obtained model is presented in Fig. 3. It is based on description of interaction among three material models: water, steel and copper (the material of the wall). By arrows is indicated the decomposition of the sub-models to other low-level models. For example, the steel material model is a description of interaction of liquid steel model with solid steel model based on the temperature evolution as reference variable. In order to obtain right models two interfaces were used: for heat transfer, for material (liquid plus solid) flow.

The cooling model is designed in order to be able to use for both cooling stages: primary and secondary, by right settings of transport variables. The models for liquid and solid phase of the processed material (steel) are presented in the following. Also, the models for steel and cooling process is presented after Fig. 3.

```
model SteelSolid
    PortThermoFluid tfa,tfb, tfc;
    PortHeat hb;
   extends SteelSolidProperties;
   Temperature T (start=800+273);
   Volume vol(start=1, min=0.1);
                 …
equation
//energy balance:
vol * rho * shcap * der(T) =
hout + hin + hb.qheat;
//mass balance:
der(vol) =tfa.qvol + tfb.qvol  +  tfc.qvol ;
        …
end SteelSolid;
```

```
model SteelLiquid
   PortThermoFluid tfa,tfb, tfc;
   Extends SteelLiquidProperties;
   Temperature T (start=1500+273);
   Volume vol(start=1, min=0.1);
                 …
equation
// mass balance:
der(vol) = tfa.qvol + tfb.qvol + tfc.qvol ;
//energy balance:
vol * rho * shcap * der(T) =
 hin + hout - der(M*L);
        …

end SteelLiquid;
```

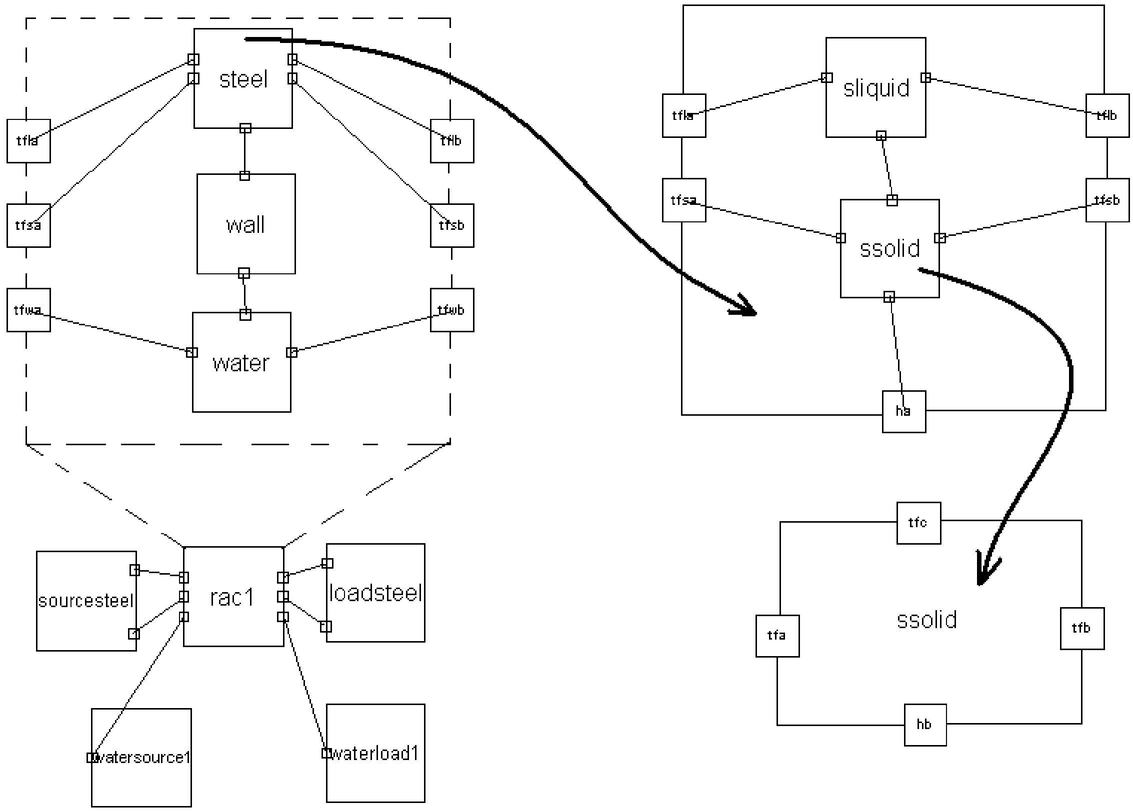

Figure 3: Decomposition of the cooling model in material sub-models

```
model Steel
// interfaces, parameters, and sub-models;
equation
    connect(tfla, sliquid.tfa);
    connect(sliquid.tfb, tflb);
    connect(ssolid.tfa, tfsa);
    connect(ssolid.tfb, tfsb);
    connect(sliquid.tfc, ssolid.tfc);
    connect(ssolid.hb, ha);
    sliquid.vol + ssolid.vol = vol;
    ssolid.tfc.T = if sliquid.vol > 0
              then sliquid.Ts else ssolid.T;
    // un-defined: vol;
     which is context dependent;
end Steel;
```

```
model Cooling
// interfaces, parameters, and sub-models;
equation
   connect(steel.tfla, tfla);
   connect(steel.tflb, tflb);
   connect(steel.tfsa, tfsa);
   connect(steel.tfsb, tfsb);
   connect(steel.ha, wall.ha);
   connect(wall.hb, water.ha);
   connect(water.tfa, tfwa);
   connect(water.tfb, tfwb);
   steel.vol = 3;
   water.vol = 0.5;
end Cooling;
```

4. SIMULATION RESULTS

The simulation scenario considers that the liquid steel is already in the ladle and is added to tundish all time in order to have a constant level of the steel inside of the tundish. Some simulation results are presented in Fig. 4, e.g., for the temperatures inside of the ladle and of the tundish, in Kelvin. The discontinuity in the temperature of the ladle should be interpreted as a change of the ladle and not by a real variation. The obtained results are in the same range like those obtained from experimental and quite expensive measurements [6].

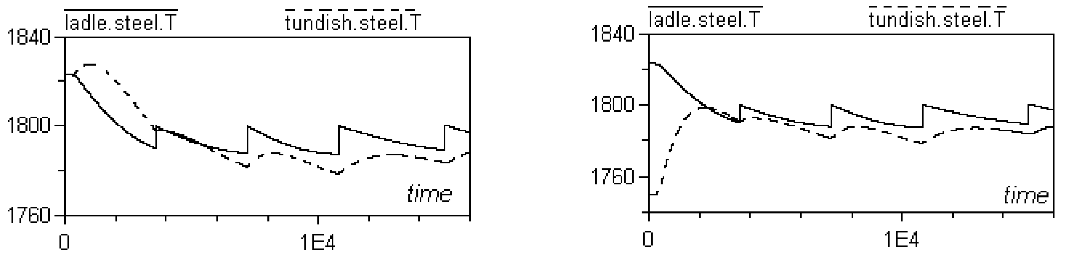

Figure 4: Temperature evolution in the ladle and tundish models

5. CONCLUSIONS

The paper's goal was to present some partial results in the modelling of continuous casting process of materials in order to generate qualitative information ready to use in a multi-level control strategy. The adopted formalism is based on object-technology and description of the running phenomena. The used language is Modelica as powerful declarative modelling and representation language. Based on a multi-layer structure of the model the behaviour of the process is obtained by describing the interaction of phase materials under energy equilibrium. The simulation results show the fidelity of the model. Further work and efforts must be done to improve the material properties and to include more low-level granularity of phenomena.

REFERENCES

[1]. B.G. Thomas, (1999), "Continuous Casting: Modeling, "*The Encyclopedia of Advanced Materials*, (J. Dantzig, A. Greenwell, J. Michalczyk, eds.) Pergamon Elsevier Science Ltd., Oxford, UK, Vol. 2, 2001, 8p., (Revision 3, Oct. 12, 1999).
[2]. Brian G. Thomas, Hua Bai, Sivaraj Sivaramakrishnan, and S. Pratap Vanka, (1999), Detailed Simulation of Flow in Continuous Casting of Steel using K-e, LES, and PIV, *Presented at "International Symposium on Cutting Edge of Computer Simulation of Solidification and Processes"*, Osaka, Japan, Nov. 10-14.
[3]. David Thomas Creech, (1997), Computational modeling of multiphase turbulent fluid flow and heat transfer in the continuous slab casting mold, *Master of Science in Mechanical Eng. Thesis*, Univ.of Illinois at Urbana-Champaign, USA.
[4]. Bruce Koza and Joseph Dzierzawski, (2000), Continuous Casting of Steel: Basic Principles, *Research article, American Iron and Steel Institute, Learning Center,* http://www.steel.org/learning/howmade/concast.htm#2, 2000.
[5]. Heinz Engl, (2000), *Industrial Mathematics Institute*, http://www.indmath.uni-linz.ac.at.
[6]. SIDEX Galati, (1983), Instructiuni tehnologice pentru turnarea continua a otelului in sleburi, pe masina de turnare cu fir si cristalizator curb, model "S".