Object Oriented Own-Built Model Library of Non-linear Thermo-Fluid Dynamic Systems in Matlab/Simulink

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Abstract:

An object oriented model library of thermo-fluid dynamic systems has been established in Matlab/Simulink. This library is useful for those who wish to create a model of demanded accuracy and don't know about the modelling of thermo-fluid dynamic systems. Using this library, modelling can be done in building simulators, engineering modelling, education purposes and for the power plant supplier companies in the sense to show their clients different types of power plant systems in simulated form which can be adopted according to the client desire. Also it can be utilized the already built power plants for extension and repairing purposes. This library has been utilized to build a Non-linear Dynamic Model of a Thermal Power Plant and a Hydraulic Actuator with a very simple way feeling that one is constructing a 2-D AutoCAD drawing.

Keywords***:*** *modelling, simulation, thermal power plants, hydraulic systems, model libraries.*

1. Introduction

Now a days complex system models are used often in simulation. Simulation is important since it provides the possibility by means of a model to study the behaviour of a complex plant model and draw conclusions concerning the real world system. Also it is very difficult to train an operator and perform experiments on an actual plant. There is a need for a simulator equipped with an interface that corresponds to the real conditions in the operation room. A computer-based plant model for such a simulator achieves a reduction of development time, costs and risks in comparison with manufacturing and testing numerous hardware prototypes, which are not feasible in a laboratory environment or a research centres.

In the modeling of an industrial process, the modeler has to perform a difficult job of transforming a physical description in terms of balance and constitutive equations into an explicit ordinary differential equations (ODE) system form. Many commercial simulation packages exist which can solve these equations, but provides very little help in building the model. There exists a lot of quit good static model for many industrial processes used for process design and steady state operations. Static design models are quite complex and they don't capture dynamics. On the other hand also there exists linear dynamic models and nonlinear dynamic data based black box type models obtained through identification using some tools such as neuro-fuzzy or neural networks, but all of them are suitable for certain range of operation. Our goal is to develop moderately complex nonlinear models that capture the key dynamical properties over a wide operation range.

In our paper [12, 17, 18, 25], the details of Human Machine Interface (HMI) in a PC based simulation of a nonlinear model of a coal-fired steam boiler were presented. The HMI is an important instrument in creating training simulators. It has been developed for data exchange between a Matlab-Simulink model of a steam boiler and an InTouch visualization program. InTouch is a commonly used program in professional power plant control rooms. It is a software package used to create a PC based man-machine interface. The interface between Matlab and InTouch is based on the Dynamic Data Exchange (DDE) protocol. During a DDE conversation, the client and server applications exchange data. This model library will provide a good model for HMI.

2. Object Oriented Non-linear Dynamic Model Library

Object oriented modelling describes each part of the model as an object with certain behaviour. Each object is formulated from basic physical laws and it needs few parameters mostly from construction data. The goal is to develop moderately complex non-linear models that capture the key dynamical properties over a wide operation range. All the modelling has been performed in software package Matlab/Simulink. Building a model form this library is very and during modelling one can feel that he is constructing an AutoCAD drawing of the model. In this way every one is able to build a model of his own choice very easily without deep knowledge of modelling. The modelling of all the modules is based on the three conservation laws.

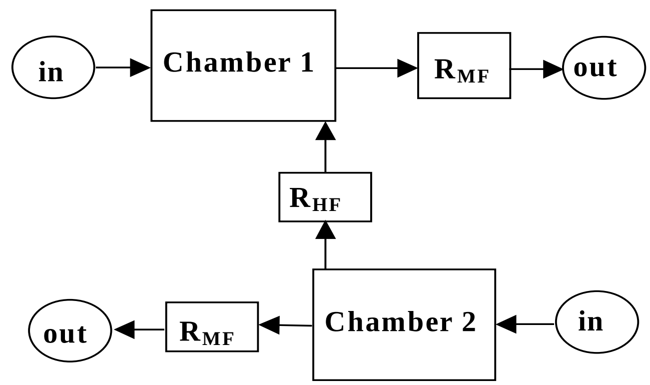


Fig. 1 Heat exchanger layout

Mass conservation:

$$\frac{dm}{dt} = \sum q_i - \sum q_o$$

Energy conservation:

$$\frac{dE}{dt} = \sum \Delta Q + \sum q_i h_i - \sum q_o h_o - \sum \frac{dW}{dt}$$

Momentum conservation:

$$\frac{d(mv)}{dt} = \sum q_i v_i - \sum q_o v_o + \sum F$$

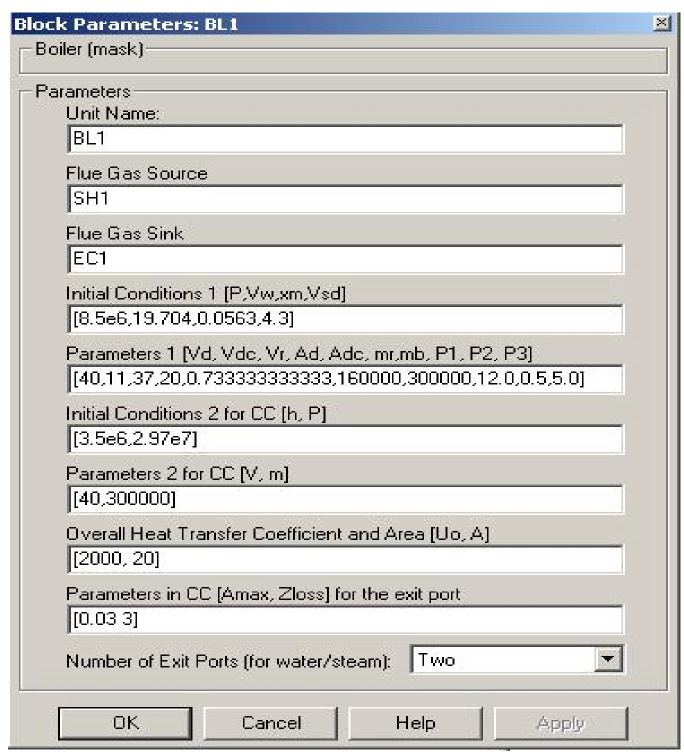
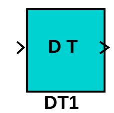


Fig. 2 Drum boiler menu for parameter setting

For simulation point of view and providing user-friendly atmosphere, modelling has been made such that a dialogue box will appear by clicking the mouse over the model (object) as shown in Fig. 2. Initial conditions and parameters of the block can be entered through this display window. The chambers are divided mainly in two groups. One in which the water and steam flows, and other in which flue gases flows. Data in form of a vector of ten variables are obtained from each unit; in which first six (flow, enthalpy, pressure, temperature, quality, total head) are common to all chambers and other four depend on chamber (e.g. in boiler they are level, volume of water, volume of steam and steam quality at the riser exit). In case of flue gases, data in form of a vector of five variables (flow, enthalpy, pressure, temperature, heat) are obtained.

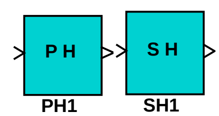
The primary unit of the library is given the name unit. For example boiler chamber, valve, pump etc. are units. Units are combined in a sub-model. For example boiler, which is a heat exchanger as shown in Fig. 1, is a sub-model. In chamber 1, water enters and leave as steam passing through a flow resistance, while in chamber 2 hot flow gases enters and leave with heat loss through a flow resistance. Theses two chambers are connected through a heat resistance.

3. Matlab/Simulink Model Library



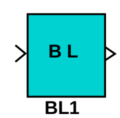
Two Phase Units

These are the units, which can be used in the chambers where the water is at saturation point or phase change occurs, for example boilers, condensers, deaerator tank. A highly non-linear dynamic model with two state variables, pressure and volume of water has been derived from conservation equations.



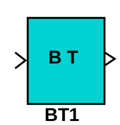
Single Phase Units

These are the units, which can be used in the chambers where exist only single phase For example water at sub-cooled or super heated states. Two different types of single-phase units exist for water-steam and flue gases. A nonlinear dynamic model with two state variables, specific enthalpy and pressure has been derived from conservation equations



Drum Boiler Unit

Two-phase unit captures the behaviour of a saturated water-vapour container quite well but in case of the drum boiler it does not capture the behaviour of the drum level because it does not describe the distribution of water and steam in drum. So a fourth order model have been derived for boiler. This model is similar to the well-known Astrum model but differs in some parameters and formulation. Neuro-Fuzzy and Neural Networks algorithms will be used to identify parameters from the data obtained from normal plant operation. Pressure, volume of water and steam in drum and steam quality at the riser exit is taken as state variable.



Water Storage or Buffer Tank Unit

These tanks are usually at normal pressure and temperature, sot its dynamics are captured by single state which is the volume of water in the tank.

Media Flow Resistance Unit

Media flow resistances are used to connect two chambers with each other. Basically there are two types of flow, incompressible e.g. as water and compressible as steam and flue gases, for both separate equations are derived from momentum balance equation. For water-steam and flue gases separate units are modelled.

Heat Flow Resistance Unit

As shown in Fig. 1, two chambers are connected through a heat flow resistance unit. Heat flow has been calculated using the well-known formula for heat exchangers:

$$\Delta Q = U_{overall}\ A\,\Delta T_{LMTD} = R_{HFR}\Delta T_{LMTD}$$

where R_{HFR} is the product of overall heat transfer coefficient and surface area and ΔT_{LMTD} is the Log Mean Temperature Difference. $U_{overall}$ will be identified from data using neuro-fuzzy and neural networks.

Burner Unit

Burner is a device where combustion of fuel e.g. coal takes place. It consists of two parts, in the first part chemical reaction of the coal has been modelled which calculates the required amount of air, heat of combustion, ashes, amount of residual oxygen in exhaust flue gases and molecular weight of flue gases. In the second part the pressure and enthalpy of the flue gases in the combustion chamber is taken as state variables. These flue gases are then supplied to the gas chambers of super heater, boiler etc. through flow resisters.

Turbine and Pump Units

The principle of turbine and pump is the same but turbine delivers work and pump utilizes external work. Both are modelled separately. Turbine has two parts one is the fluid part where a single-phase unit formulation has been applied as pressure and enthalpy as state variables, and the other is the mechanical part where the velocity is the state variable. Similar is the case of pump.

Separator, Mixer and Cooler Units

Separators are units applied to the points where the flow is supplied to two different chambers from one chamber. Similarly mixers are used where flow from two chambers are mixed to supply to a single chamber. Coolers are devices in which water is sprayed to superheated steam to lower its temperature.

Differential Hydraulic Cylinder

Modelling of this block has been done using four state variables. A state space method has been used to represent the non-linear model of the cylinder.

Spool valve

Second order differential equation has been used to describe this block.

Miscellaneous Units

There are many other units available for example steam table, which calculates all the thermodynamic properties of sub-cooled water, saturated water/steam and super-heated steam, molecular weight of any mixture of gas and its all thermodynamic properties. Still work is going on to build as many as units.

4. Modelling of a Thermal Power Plant

A typical thermal power plant layout has been taken which can be found in books as shown in Fig. 3. Thermal power plant consists of many parts e.g. boiler, preheater, pumps, valves etc. For this reason object oriented modelling is suitable for this. Condensed water is pumped from the condenser to the deaerator via a preheater. The deaerator is used to remove the dissolve gases from water by raising the temperature of water to its saturation temperature using hot steam from boiler. The feed water is then pumped from the deaerator to the drum via an economizer, which heats up the water to boiling temperature. The water in the drum is circulated through the evaporator, and the two phases-water and steam then separate into the drum. Saturated steam is extracted from the drum and passes through two super-heaters to produce super-heated steam before it enters the steam turbine. To control the tempera-

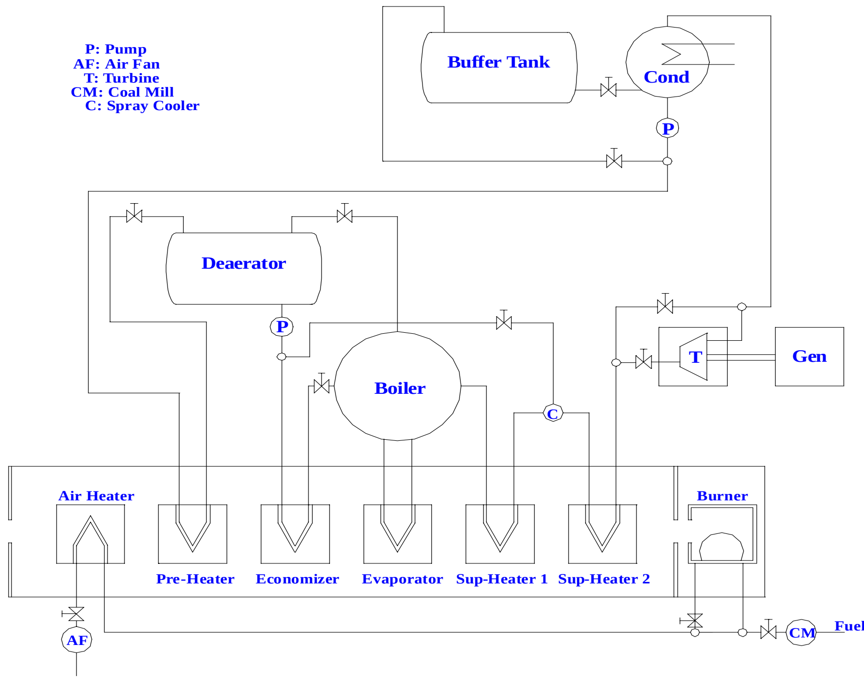


Fig. 3 Functional scheme of a Thermal Power Plant

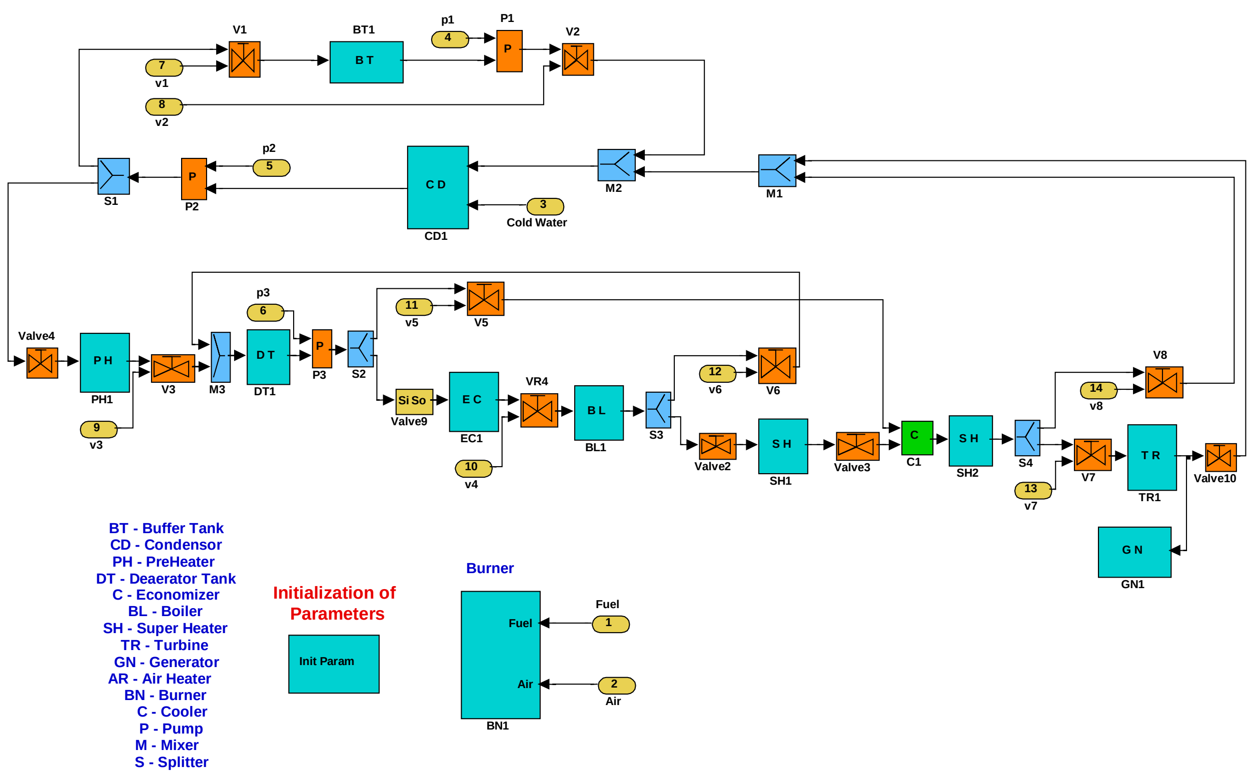


Fig. 4 Matlab/Simulink diagram of a Thermal Power Plant

ture of the steam a spray cooler is placed between the super heaters. In the turbine the steam flow expands due to low pressure, and it is then condensed to water again in the condenser and can be recirculated to the deaerator

To built a Simulink model from the layout as shown in Fig. 3 blocks for different parts of the plant are taken from the library and placed in the sequence of flow of water/steam. Starting from condenser blocks representing different units are placed and is connected through valves, pumps etc. Initial conditions and parameters are entered through dialog windows. If there will be some flaw in initial conditions of state variables, after a run the steady state condition will be automatically achieved after certain time. Also it should be noted that the steady state condition also depends upon parameters and external inputs so desired steady state condition can be achieved by varying the parameters e.g. valve opening, pump pressure etc. Also locks exist through which parameters can be altered during running the simulation.

5. Modelling of a Differential Hydraulic Actuator

The schematic diagram for a differential hydraulic actuator has been shown in Fig. 5. Full details of the mathematical modelling have been discussed in the papers [8,9,10] where a special attention is paid the integral wind-up.

The dynamics of the cylinder has been modelled by blocks with four state variables: position and velocity of the piston, pressures in chamber 1 and 2, while the dynamics of the spool valve represent two state variables - position and velocity of the piston. To make the model as close as to the real, all the phenomena present in real system has been considered. For example static, viscous and Coulomb frictions, anti-windup, dead time in spool valve, oil leakage.

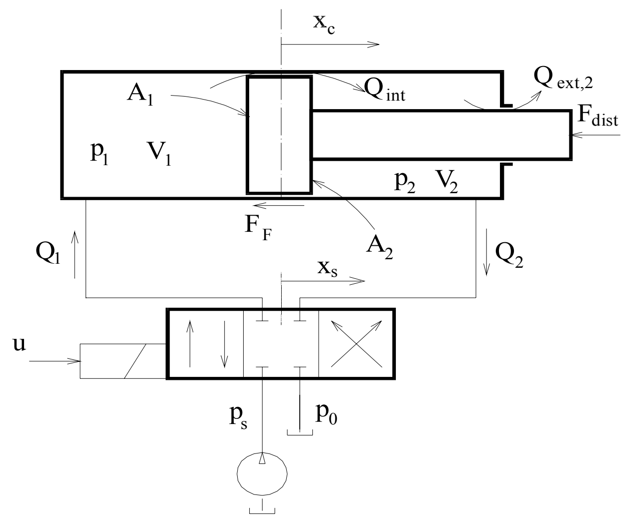


Fig. 5 Schematic diagram of a differential hydraulic cylinder

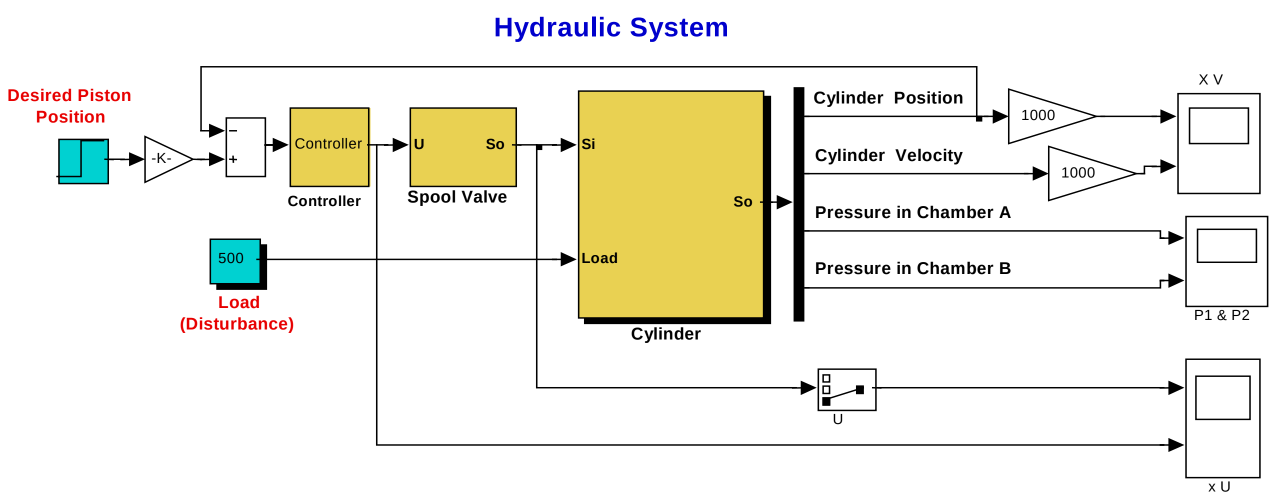
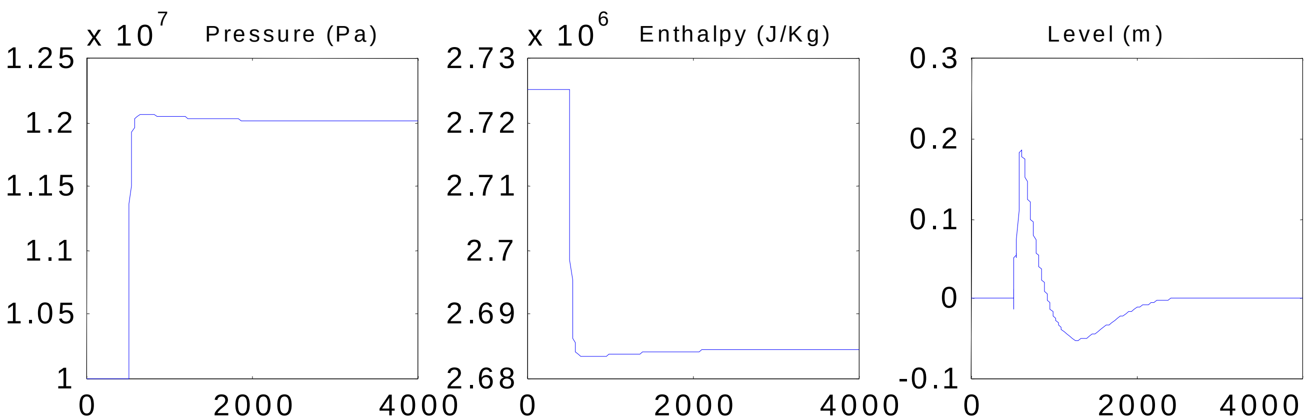


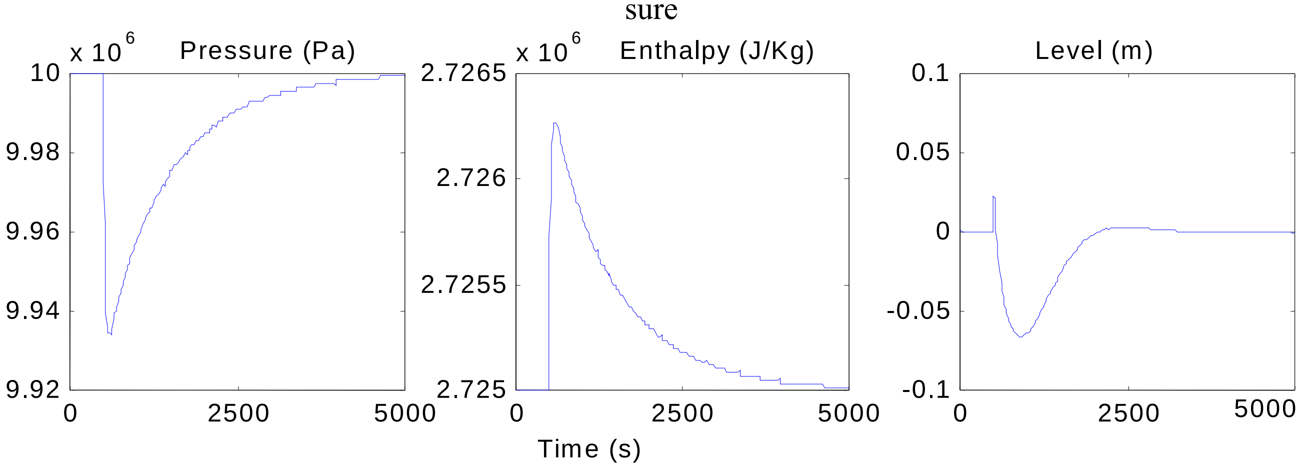
Fig. 6 Matlab/Simulink diagram of a differential hydraulic actuator

6. Conclusions

An object oriented non-linear model library for modelling of thermo-fluid dynamic systems has been established. This library is very useful for those who don't knows about modelling as well as useful for those who knows about modelling as it will accelerate their work.
Using this library modelling can be done in building simulators, engineering modelling, education purposes. This library has been utilized to build a Non-linear Dynamic Model of a Thermal Power Plant and a hydraulic actuator with a very simple way feeling that one is constructing a 2-D AutoCAD drawing. Some of the results for the dynamics in drum boiler have been shown in *Fig. 7* and some results in the simulation of hydraulic actuator has been given in *Fig. 8*.



Responses in drum boiler for step increase of desired pressure



Responses in drum boiler for step increase of 5 kg/s in steam flow

Fig. 7 Responses in drum boiler

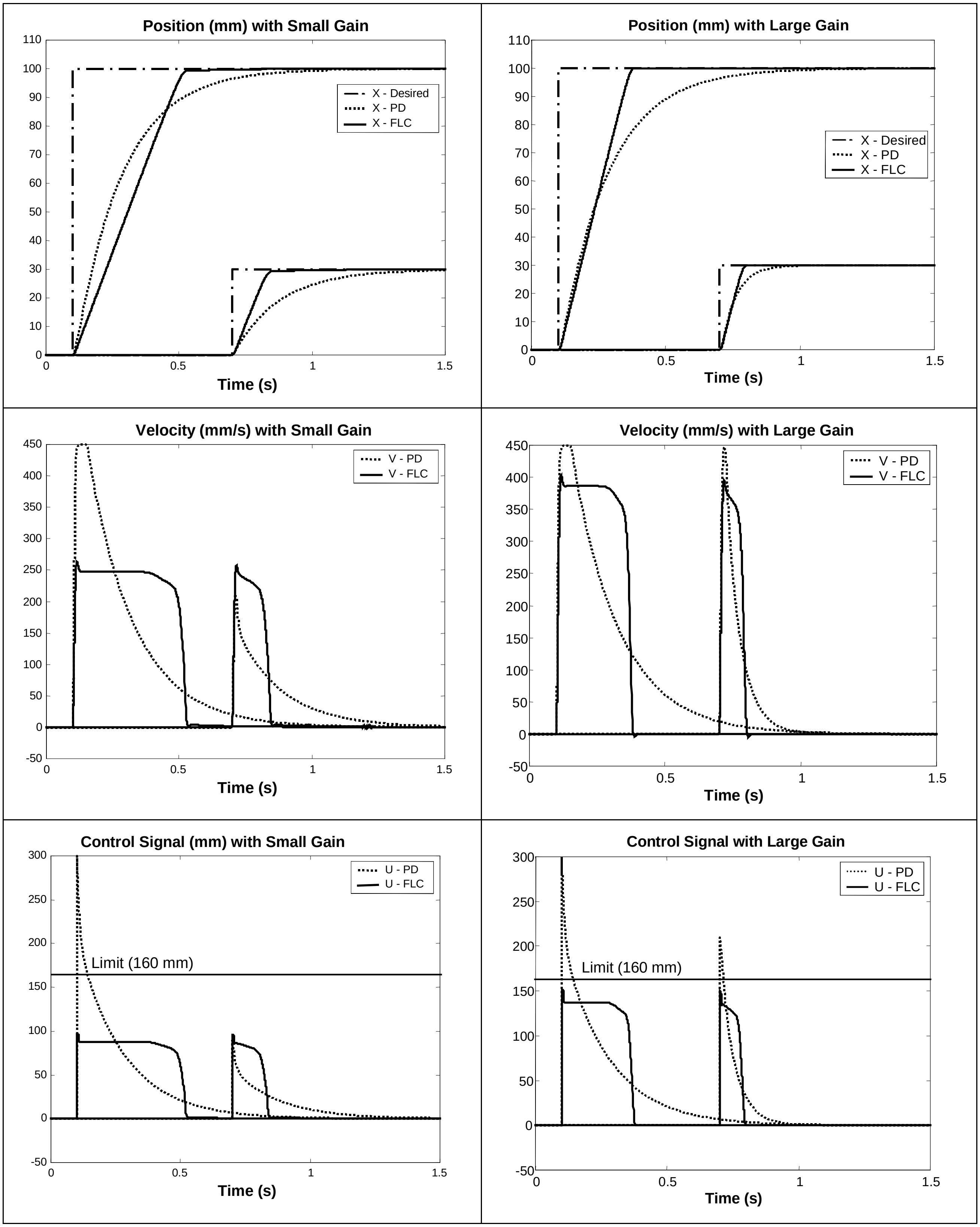


Fig. 8 Comparison of PD and FL control for different gains, step sizes and velocity limitations

7. Acknowledgement

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