BENCHMARK PID 2012

The Matlab & Simulink files to approach the Boiler Control Problem

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1. INTRODUCTION

This document is an appendix to the "Benchmark for PID control based on the Boiler Control Problem". It contains a brief description of the Matlab & Simulink files provided in the Benchmark PID 2012. They have been developed with Matlab (Version 7.0.4) and Simulink (Version 6.2) (R14) Service Pack 2. But also have been checked in Matlab (Version 7.6) and Simulink (Version 7.1) Release 2008a.

The files have been grouped as follows: MIMO files, in order to approach the multivariable boiler control problem, SISO files, in order to approach boiler control problem, and COMMOM files necessary in both approaches. But in any case, it is very important to follow some advices in order to take advantage of this benchmark.

1) You must preserve the structure of the Simulink models, replacing only the corresponding single loop or multivariable controller in the file *Boiler_*Control_PID12.mdl*.
2) You must use the same values for *Uo*, *loadlevel*(1,2), *uo*, *xo* and *Yo* in all the experiments. The containers of these data are the files *dat_in_boiler_*.mat*.
3) You should configure the experiments using the variables *Yf*, *loadlevel*, *tchange*, *time* and *ts*. Their default values are also in the files *dat_in_boiler_*.mat*. You can modify these values using mat files or editing the program file *Test_Boiler_*Control.m*.
4) You should incorporate the controller data editing the program file *Test_Boiler_*Control.m*.
5) At the end of the simulations you must save at least the variables *t*, *registers*, *tchange*, *Yo* and *Yf*. The files *test*Boiler*.mat* are examples of simulations.
6) You should report indexes evaluated with the functions *JBoiler*.p*, reporting also the weighting factor (*w*) used for the RIAVU indexes.

2. FILES TO APPROACH THE MIMO BOILER CONTROL PROBLEM

The benchmark provides the following 11 files in order to approach the multivariable boiler control problem:

Boiler_MIMOControl_Evaluation.m
Boiler_MIMOControl_PID12.mdl
JBoilerMIMO.p
Test_Boiler_MIMOControl.m
dat_in_boiler_mimo.mat
dat_in_boiler_mimo1.mat
dat_in_boiler_mimo2.mat

test1BoilerMIMO_CL1.mat
test1BoilerMIMO_CL2.mat
test2BoilerMIMO_CL1.mat
test2BoilerMIMO_CL2.mat

Boiler_MIMOControl_PID12.mdl This Simulink model is ready to test any multivariable controller, with or without feedforward, operating the boiler in different scenarios. The controller needs to be a 5x2 Simulink block and should to replace the decentralized PID controller included by default in the Benchmark PID 2012. The only requirement is that all experiments should start from the same operating point. Therefore all the elements in the model must be appropriately initialized before the simulation. Both things, the initialization and the simulation, can be carried out with the program *Test_Boiler_MIMOControl*.

Test_Boiler_MIMOControl.m This Matlab program is designed to test any multivariable controller operating the boiler in different scenarios. The procedure suggested is always the same: first a mat file with model data and simulation signals is loaded, second the multivariable controller is parameterized, third the simulation is executed, and fourth the simulation results are shown and saved for evaluation. The file provided in the Benchmark PID 2012 is prepared to test a decentralized PID controller, loading model data and simulation signals from the file *dat_in_boiler_mimo.mat* and saving the simulation results in the file *testBoilerMIMO_CL.mat*.

Boiler_MIMOControl_Evaluation.m This Matlab program is designed to do a comparative evaluation of two multivariable controllers. The only requirement is that the controllers had been previously tested in the same experiment. One of them plays the role of controller of reference and the other one plays the role of controller to evaluate. The procedure suggested is always the same: first a mat file with simulation results of reference is loaded, second a mat file with simulation results to evaluate is loaded, and third the comparative evaluation is done. The file provided in the Benchmark PID 2012 is prepared to load simulation results from the files *test1BoilerMIMO_CL1.mat* and *test1BoilerMIMO_CL2.mat*.

dat_in_boiler_mimo.mat. This mat file contains the model data and the simulation signals used to select the initial operating point and to configure the corresponding experiment. The values of *Uo*, *loadlevel*(:,2), *uo*, *xo* and *Yo* must be preserved in order to start all the experiments from the same operating point. It is given by: Fuel flow ≅ 35.21%, Water flow ≅ 57.57%, Load level ≅ 46.36%, Steam pressure = 60%, Oxygen level = 50%, Water level = 50%. The provided values are: *Uo*=[35.2139; 57.5742], *loadlevel*(1,1)=0, *loadlevel*(1,2)=46.3642, *uo*=[0.4069; 0.4981; 0.5757], *xo*=[22; 2.5; 655.4319; 0.25], *Yo*=[60; 50; 50].
The values of *Yf*, *loadlevel*, *tchange*, *time* and *ts* can be modified to configure the different scenarios. The default values configure a standard experiment with duration of 2000 seconds and sampling period of 1 second, including a 20% step load level change at t=100 s. Their values are: *Yf*=[60; 50; 50] (identical to *Yo*), *loadlevel*=[0 46.3642; 99.80 46.3642; 100 66.3642; 2000 66.3642], *tchange*=100 (unnecessary in this case), *time*=2000 and *ts*=1.

dat_in_boiler_mimo1.mat. This mat file is similar to *dat_in_boiler_mimo.mat*. In this case an experiment type 1 has been configured. The duration of the experiment is 4200 seconds, including a profile of load level. First the load increases in ramp from t=100 s until reach the 70% in t=500 s, second the load remains constant, third the load decreases in ramp from t=2000 s until reach the initial operating point in t=2400 s, where it remained until t=4200 s. This is possible with *loadlevel*=[0 46.3642; 100 46.3642; 500 70; 2000 70; 2400 46.3642; 4200 46.3642].

dat_in_boiler_mimo2.mat. This mat file is similar to *dat_in_boiler_mimo.mat*. In this case an experiment type 2 has been configured. The duration of the experiment is 2000 seconds, including a 5% step change in the steam pressure setpoint at t=100 s. This is possible with: *Yf*=[65; 50; 50] (compare with *Yo*), *loadlevel*=[0 46.3642; 2000 46.3642] and *tchange*=100.

test1BoilerMIMO_CL1.mat. This mat file contains the results generated by simulation in the multivariable boiler control problem. It must at least contain the time vector (*t*) and the signals (*registers*) generated in the simulation, the setpoint change instant (*tchange*), the initial (*Yo*) and final values (*Yf*) of the process outputs. In this case a decentralized PID controller was tested trying to follow the profile of load level configured through *dat_in_boiler_mimo1.mat*.

test1BoilerMIMO_CL2.mat. This mat file contains the results generated operating the boiler in the same conditions that the file *test1BoilerMIMO_CL1.mat*. Only some control parameters have been modified.

test2BoilerMIMO_CL1.mat, ***test2BoilerMIMO_CL2.mat***. This mat files contain the boiler response to a step change in the steam pressure setpoint configured through *dat_in_boiler_mimo2.mat*. The same decentralized PID controller has been used, only some control parameters have been modified.

JBoilerMIMO.p This Matlab function evaluates the seven individual performance indexes and the combined index proposed in the comparative evaluation for the multivariable boiler control problem. The input arguments for the function are: the time vector and the signals generated in the simulation of reference, the time vector and the signals generated in the simulation to evaluate, the setpoint change instant, the initial and final values of the process outputs, the weighting factor for the RIAVU indexes.

3. FILES TO APPROACH THE SISO BOILER CONTROL PROBLEM

The benchmark provides the following 11 files in order to approach the multivariable boiler control problem:

Boiler_SISOControl_Evaluation.m
Boiler_SISOControl_PID12.mdl
JBoilerSISO.p
Test_Boiler_SISOControl.m
dat_in_boiler_siso.mat
dat_in_boiler_siso1.mat

dat_in_boiler_siso2.mat
test1BoilerSISO_CL1.mat
test1BoilerSISO_CL2.mat
test2BoilerSISO_CL1.mat
test2BoilerSISO_CL2.mat

Boiler_SISOControl_PID12.mdl This Simulink model is ready to test any single loop controller, with or without feedforward, operating the boiler in different scenarios. The controller needs to be a 3x1 Simulink block and should to replace the PID controller included by default in the Benchmark PID 2012. The only requirement is that all experiments should start from the same operating point. Therefore all the elements in the model must be appropriately initialized before the simulation. Both things, the initialization and the simulation, can be carried out with the program *Test_Boiler_SISOControl*.

Test_Boiler_SISOControl.m This Matlab program is designed to test any single loop controller operating the boiler in different scenarios. The procedure suggested is always the same: first a mat file with model data and simulation signals is loaded, second the single loop controller is parameterized, third the simulation is executed, and fourth the simulation results are shown and saved for evaluation. The file provided in the Benchmark PID 2012 is prepared to test a PID controller, loading model data and simulation signals from the file *dat_in_boiler_siso.mat* and saving the simulation results in the file *testBoilerSISO_CL.mat*.

Boiler_SISOControl_Evaluation.m This Matlab program is designed to do a comparative evaluation of two single loop controllers. The only requirement is that the controllers had been previously tested in the same experiment. One of them plays the role of controller of reference and the other one plays the role of controller to evaluate. The procedure suggested is always the same: first a mat file with simulation results of reference is loaded, second a mat file with simulation results to evaluate is loaded, and third the comparative evaluation is done. The file provided in the Benchmark PID 2012 is prepared to load simulation results from the files *test1BoilerSISO_CL1.mat* and *test1BoilerSISO_CL2.mat.*

dat_in_boiler_siso.mat. This mat file contains the model data and the simulation signals used to select the initial operating point and to configure the corresponding experiment. The values of *Uo*, *loadlevel*(:,2), *uo*, *xo* and *Yo* must be preserved in order to start all the experiments from the same operating point. It is given by: Fuel flow ≅ 35.21%, Load level ≅ 46.36%, Steam pressure = 60%, Oxygen level = 50%, Water level = 50%. The provided values are: *Uo*=35.2139, *loadlevel*(1,1)=0, *loadlevel*(1,2)=46.3642, *uo*=[0.4069; 0.4981; 0.5757], *xo*=[22; 2.5; 655.4319; 0.25], *Yo*=[60; 50; 50].

The values of *Yf*, *loadlevel*, *tchange*, *time* and *ts* can be modified to configure the different scenarios. The default values configure a standard experiment with duration of 2000 seconds and sampling period of 1 second, including a 20% step load level change at t=100 s. Their values are: *Yf*=[60; 50; 50] (identical to *Yo*), *loadlevel*=[0 46.3642; 99.80 46.3642; 100 66.3642; 2000 66.3642], *tchange*=100 (unnecessary in this case), *time*=2000 and *ts*=1.

dat_in_boiler_siso1.mat. This mat file is similar to *dat_in_boiler_siso.mat*. In this case an experiment type 1 has been configured. The duration of the experiment is 4200 seconds, including a profile of load level. First the load increases in ramp from t=100 s until reach the 70% in t=500 s, second the load remains constant, third the load decreases in ramp from t=2000 s until reach the initial operating point in t=2400 s, where it remained until t=4200 s. This is possible with *loadlevel*=[0 46.3642; 100 46.3642; 500 70; 2000 70; 2400 46.3642; 4200 46.3642].

dat_in_boiler_siso2.mat. This mat file is similar to *dat_in_boiler_siso.mat*. In this case an experiment type 2 has been configured. The duration of the experiment is 2000 seconds, including a 5% step change in the steam pressure setpoint at t=100 s. This is possible with: *Yf*=[65; 50; 50] (compare with *Yo*), *loadlevel*=[0 46.3642; 2000 46.3642] and *tchange*=100.

test1BoilerSISO_CL1.mat. This mat file contains the results generated by simulation in the multivariable boiler control problem. It must at least contain the time vector (*t*) and the signals (*registers*) generated in the simulation, the setpoint change instant (*tchange*), the initial (*Yo*) and final values (*Yf*) of the process outputs. In this case a PID controller was tested trying to follow the profile of load level configured through *dat_in_boiler_siso1.mat*.

test1BoilerSISO_CL2.mat. This mat file contains the results generated operating the boiler in the same conditions that the file *test1BoilerSISO_CL1.mat*. Only some control parameters have been modified.

test2BoilerSISO_CL1.mat, ***test2BoilerSISO_CL2.mat***. This mat files contain the boiler response to a step change in the steam pressure setpoint configured through *dat_in_boiler_siso2.mat*. The same PID controller has been used, only some control parameters have been modified.

JBoilerSISO.p This Matlab function evaluates the five individual performance indexes and the combined index proposed in the comparative evaluation for the multivariable boiler control problem. The input arguments for the function are: the time vector and the signals generated in the simulation of reference, the time vector and the signals generated in the simulation to evaluate, the setpoint change instant, the initial and final values of the process outputs, the weighting factor for the RIAVU indexes.

4. COMMON FILES TO APPROACH THE BOILER CONTROL PROBLEM

The benchmark provides the following 6 common files in order to approach the boiler control problem:

PIDdiscreteA_awRRL.p
boilerstates.p
ratio_constraints_scale.p
register10.p
register15.p

register20.p

PIDdiscreteA_awRRL.p This S-function has been developed to implement in Simulink the PID controller. It is a discrete implementation of the standard PID algorithm with filter derivative, where proportional and derivative action can use the error signal or the process variable. The function includes also a reset antiwindup mechanism to guarantee that the control signal fulfils the range and rate constraints. The input arguments for the S-function are: the controller structure, the initial value for the controlled variable, the initial value for the control signal, the sampling period for control in seconds, the proportional gain, the integral time, the derivative time, the derivative filter factor, the minimum value allowed to the control signal, the maximum value allowed to the control signal, the rate limit for the control signal. Select the controller structure equal to [1 1] when you like proportional and derivative actions based on the error signal. Select [1 0] when you like derivative action based on the process variable. And [0 0] when you like proportional and derivative actions based on the process variable.

boilerstates.p This S-function has been developed to implement in Simulink the boiler dynamics. The input argument for the S-function is the internal state vector (*xo*).

ratio_constraints_scale.p This S-function has been developed to add the air flow control in ratio with the fuel, to normalize the boiler manipulated variables and to simulate the constraints in the manipulated variables.

register10.p, register15.p, register20.p These S-functions have been developed to simulate the time delays using shift registers.