Design of a PI controller with Anti-reset wind up for a Wind Tunnel

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ABSTRACT
Wind tunnel is a test facility used to simulate the flight conditions. It allows us to make a reusable prototype and test it in the tunnel in low cost. Hypersonic wind tunnels operate at hypersonic speeds ie, with a mach number greater than 6. For doing experiments, it is necessary to maintain a constant pressure in the settling chamber of the tunnel so that we get the desired mach number and mass flow rate at the nozzle output. Here, a PI controller with anti reset wind up is designed and the pressure of hypersonic intermittent blow down type wind tunnel is controlled.

Keywords:
Hypersonic wind tunnel, Tuning, PI controller, Anti reset wind up, Servo operation, Regulator operation.

1. INTRODUCTION
Wind tunnel is a facility used to investigate the aerodynamic properties of objects by passing a stream of velocity-controlled air over them.

Hypersonic intermittent blowdown-type wind tunnel is a ground based facility to simulate flight conditions of space vehicles in hypersonic flow regime. Block schematic [4] of the tunnel systems are shown in figure 1. The different subsystems are high pressure system, wind tunnel system which consists of Pressure regulating valve (PRV), Heater, Settling chamber, Nozzle, Test section, the Diffuser, Vacuum isolation valve After cooler and Vacuum Chamber.

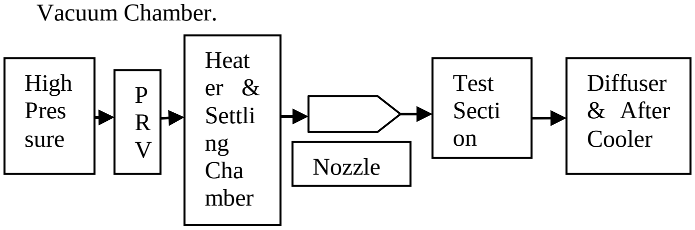

Figure 1. Block schematic of Hypersonic wind tunnel

Air is compressed and stored in the high pressure system. It is released through a pressure regulating valve to create the desired pressure in the settling chamber. Heater is used to heat the air while passing through the heater bed to avoid liquefaction when it is expanded through the nozzle to get high Mach numbers. The pressure in the settling chamber is controlled by the proper operation of the control valve so that flow through test section meets the Mach number and mass flow rate specified for the test conditions

2. MODEL OF THE SYSTEM
Obtaining the mathematical models of the wind tunnel process is very complicated since they involve viscous effects and distributed characteristics. Models of different components are developed to obtain the process model of the wind tunnel system for designing a controller considering the total system as three pressure vessels. The continuity equations [4] of the pressure vessels are used to develop the non linear model considering the effects of temperature.

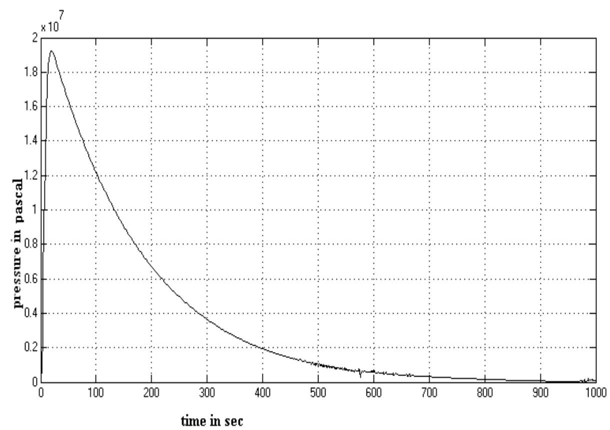

Figure 2. Open loop response curve

During the wind tunnel testing, the first vessel is charged to a pressure of 300 bar and the output valve is opened. So pressure builds up in the second and third vessel. In the third vessel the pressure increases and then reduces to zero as the air is escaping through the nozzle fitted in the third vessel at a specific mass flow rate and mach number. From the open loop response curve, it is observed that the pressure in the third vessel is increased up to 190 bar in about 10 sec, and then drops to zero in 900 sec. So the model developed is well representing the actual system behavior.

3. PI CONTROLLER.
For designing a PI controller [9], we need to know the gain K, Delay time t_d and time constant τ for calculating the controller parameters K_c and τ_i . To select the best values of the controller parameters we use controller tunning. Here we use one of the most popular empirical tuning methods, known as the process reaction curve method, developed by Cohen and Coon.

Cohen coon method is used for tuning the PI controller [10]. The process reaction curve is plotted by giving a step change from

10% opening of the valve to 20% opening. In the initial condition, ie, 10% opening of the valve, the pressure is 45 bar at time of 50 sec. When we apply a step input change of additional 10%, the pressure becomes 90 bar at time of 100sec and the process reaction curve is obtained as shown in figure 3.

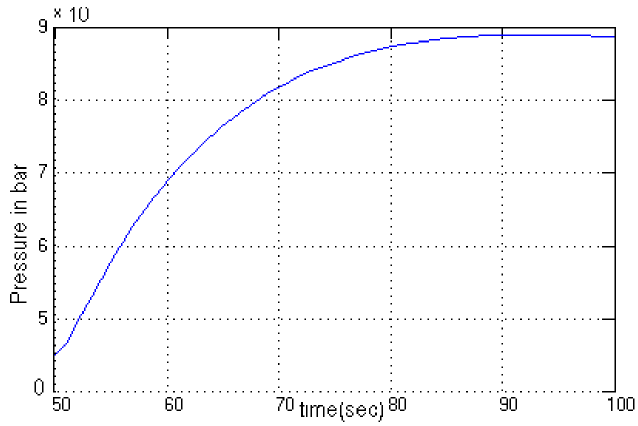

Figure 3. Process reaction curve

The proportional gain is given by

$$K_c = \frac{\tau}{Kt_d}(0.9 + \frac{t_d}{12\tau}) \text{ and}$$

The integral time is given by

$$.\tau_i = \frac{30 + 3(t_d / \tau)}{9 + 20(t_d / \tau)}$$

Using these equations, we obtained the proportional gain as K_c=5.3 and integral time as τ_i=1.6 sec.
The transfer function of the PI controller is given by,

$$\frac{U(s)}{e(s)} = K_c + \frac{K_c}{\tau_i s}$$

The integral term of a PI controller causes its output to continue changing, as long as there is a non zero error.
Often, the errors cannot be eliminated quickly, and given enough time, they produce larger and larger values for the integral term, which in turn keeps increasing the control action until it is saturated ie, the valve is completely opened or closed. This condition is called reset wind up. Then even if the error returns to zero, the control action will remain saturated.
The condition can be eliminated by providing anti- reset wind up. Now, as soon as the error changes sign, the control action can return within the control range in one sampling period.

Simulink is used for simulating the controllers. Figure below shows the simulink program of the system with PI controller.

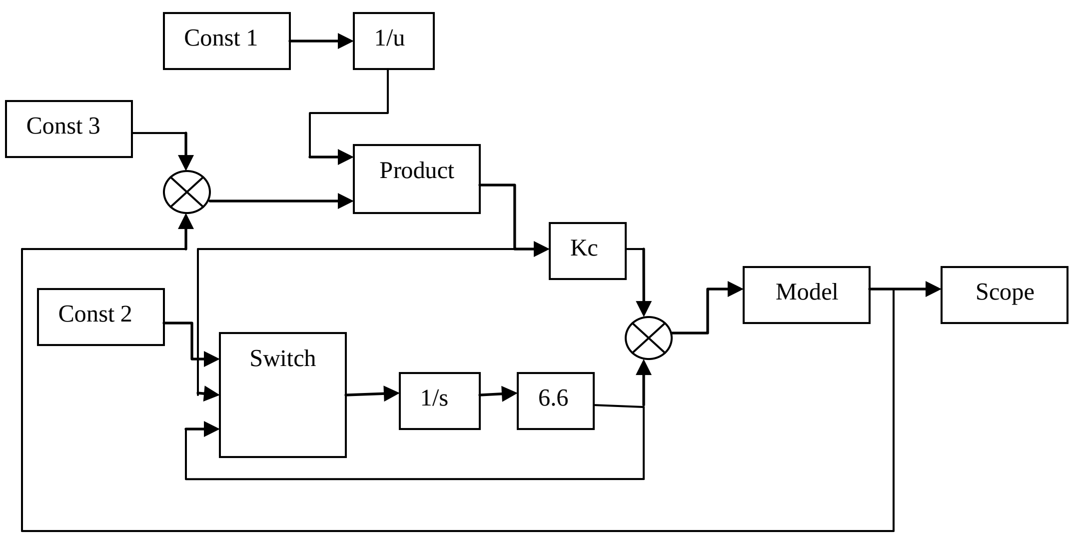

Figure 4. Simulink program of the system with Anti reset wind up PI controller.

4. SIMULATION RESULTS AND DISCUSSION

4.1ServoOperation

In servo operation, the ability of a controller to track changes in set point (requirement) is evaluated.

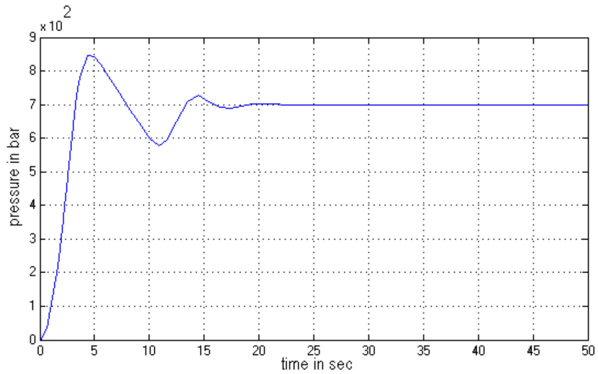

Figure 5. Output response of PI controller with anti reset wind up at set point of 70 bar

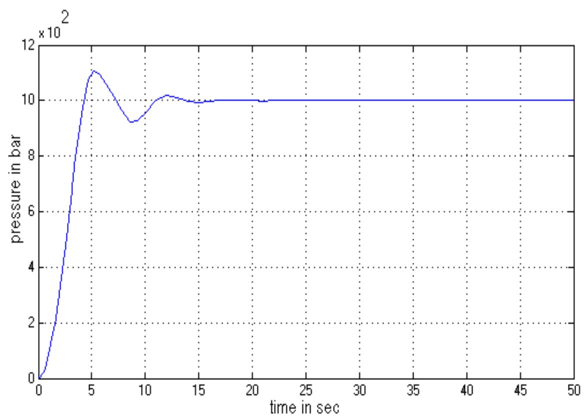

Figure 6. Output response of PI controller with anti reset wind up at set point of 100 bar

Figure 5 shows the output response of PI controller with anti reset wind up for set point of 70 bar, which settles at the set point in about 20 sec. When the set point is changed to 100 bar, the pressure settles at the set point in about 15 sec as shown in figure 6.

For the two different servo operations, IAE and ISE are calculated and is given in table 1.

Table 1. Comparison of IAE and ISE for servo operation

Servo operation	IAE	ISE
set point of 70 bar	$1.5252X10^{8}$	$7.6402X10^{15}$
set point of 100 bar	$1.7229X10^{8}$	$1.3784X10^{14}$

From the servo regulation graphs, we can see the IAE and ISE for the set point of 100 bar is more even though the time taken to settle at the set point is less compared to that of at 70 bar

4.2 Regulator Operation

In regulator operation, the ability of a controller to resist the disturbances affecting the system (load changes) is evaluated.

Figure 7 and figure 8 shows the regulation operation obtained when there is a step change in temperature from 700K to 500K at a time of 30 sec for the set point of 70 bar and 100 bar respectively. Similarly, figure 9 and figure 10 shows the regulation operation obtained when there is a step change in temperature from 700K to 900K at a time of 30 sec for the set point of 70 bar and 100 bar respectively.

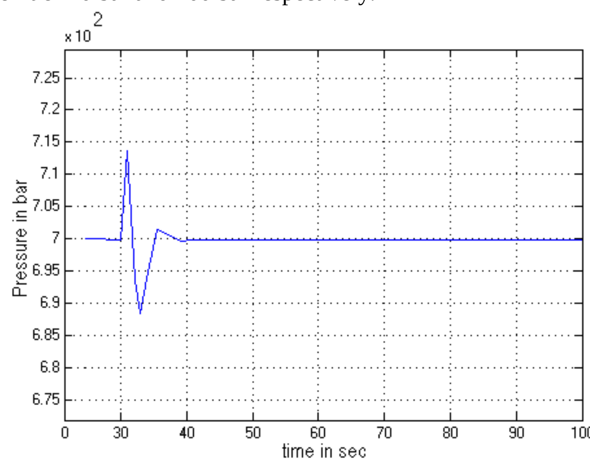

Figure 7. Step change in temperature from 700K to 500K at time of 30 sec for a set point of 70 bar.

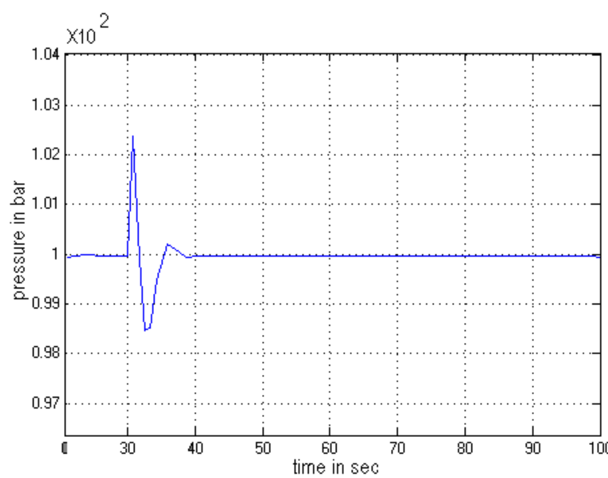

Figure 8. Step change in temperature from 700K to 500K at time of 30 sec for a set point of 100 bar.

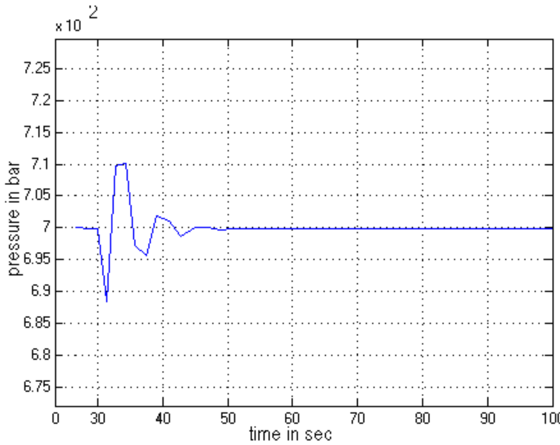

Figure 9. Step change in temperature from 700K to 900K at time of 30 sec for a set point of 70 bar.

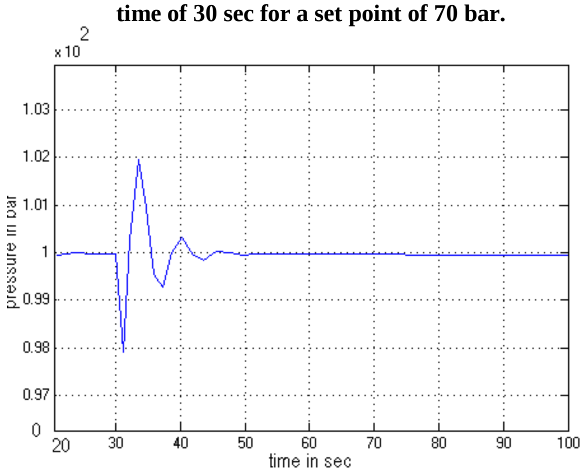

Figure 10. Step change in temperature from 700K to 900K at time of 30 sec for a set point of 70 bar.

For the different regulator operations, IAE and ISE are calculated and is given in table 2.

From the study of the regulator operations, it is found that for any step change in the temperature T_2, IAE and ISE is more for the set point of 100 bar.

Table 2. Comparison of IAE and ISE for regulator operation

Regulator operation	IAE	ISE
Step change in T_2 from 700K to 500K at time of 30 sec for a set point of 70 bar.	4.3435 $X10^5$	3.964 $X10^{10}$
Step change in T_2 from 700K to 500K at time of 30 sec for a set point of 100 bar.	7.5188 $X10^5$	1.0537 $X10^{10}$
Step change in T_2 from 700K to 900K at time of 30 sec for a set point of 70 bar.	4.683 $X10^5$	3.643 $X10^{10}$
Step change in T_2 from 700K to 900K at time of 30 sec for a set point of 100 bar.	8.213 $X10^5$	1.006 $X10^{10}$

5. CONCLUSION

A PI controller with anti reset wind up is designed and it is used to control the pressure in the settling chamber of a hypersonic wind tunnel. For different set points, the system settles. The servo and regulator operations of the system is studied, and it is found that the time taken to settle at the set point of 100 bar is less compared to that of at 70 bar, the IAE and ISE are more for the set point of 100 bar. An improvement in IAE and ISE can be obtained by using more efficient controllers.

6. REFERENCES

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