PI control for regulating pressure inside a hypersonic wind tunnel

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Abstract

This paper develops a PI controller for the control of settling chamber pressure inside a Hypersonic wind tunnel. We establish a model for the system for designing the PI control for regulating the settling chamber pressure. The effective PI control method proposed in this paper makes the settling chamber pressure to settle down in a shorter duration despite the modelled nonlinearities of the system.

Keywords- **Hypersonic wind tunnel, PI control,pressure vessel,pressure regulation,settling chamber pressure.**

I. INTRODUCTION

The PID algorithm is the most popular feedback controller used within the process industries. It has been successfully used for over 50 years. It is a robust algorithm that can provide excellent control performance despite the varied dynamic characteristics of process plant. Proportional + Integral (PI) controllers were developed because of the desirable property that systems with open loop transfer functions of type 1 or above have zero steady state error with respect to a step input[6].

Proportional action responds quickly to changes in error deviation. Integral action is slower but removes offsets between the plants output and the reference. Here PI control is applied to hypersonic wind tunnel for regulating pressure inside the settling chamber. The proposed PI control method provides the settling chamber pressure to settle faster and reduces peak overshoot. Research has shown that combination of PI control method with many other control methods like sliding mode control, neural network control, fuzzy logic control, robust control, adaptive control, etc. are also possible.

Hypersonic wind tunnel is a test facility to measure the aerodynamic forces on the space vechile in high pressure flow regime. Wind tunnels are categorised as subsonic, supersonic and hypersonic, depending on the mach number. Block schematic of the tunnel systems are shown in Fig.1. Wind tunnel system consists of high pressure system(HP), vacuum system(Vac) and wind tunnel system consisting, Pressure regulating valve(PRV), Heater(H1), Settling chamber(SC), Nozzle(NOZ), Test section(TS), Diffuser(DIFF) and Aftercooler(AFCL) [3]. Compressed air from the pressure vessel 1 is released through a pressure valve. The second vessel is a heater. Settling chamber pressure is controlled by designing a suitable controller for the effective operation of the pressure valve. Inorder to get accurate airflow, not only proper modelling but perfect controller design is required. The test specimen is placed in the test section. The maximum run time available is of the order of 20-40 sec [4]. In the actual plant present in IIT Powai, the process is completed within 10 to 15 sec.

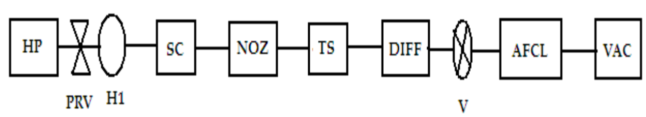


Fig. 1. **Block diagram of hypersonic wind tunnel**.

Most of the systems in the universe are nonlinear. Modelling the system with the possible nonlinearities and design a suitable nonlinear controller is complicated and time consuming. Wind tunnel system control using PI controller is discussed in here. In this paper, Section II gives the modelling of the nominal wind tunnel system. In section III, simulation of the model in open loop is presented, section IV presents the description of the plant and the simulation result with the PI controller, section V presents the the simulation result with PI controller. Finally we conclude the paper with section VI.

II. WIND TUNNEL SYSTEM MODELLING

For the purpose of modelling, the entire system is split into three pressure vessels as given in fig.(2) [3]. We consider the equations of flow rate of compressible fluid through a control valve, flow rate equation from empirical analysis, mass flow rate through nozzle and continuity equations.

A. Modelling

Flow rate of compressible fluid through a control valve [6] is given by,

$F1 = mCvN8FpP1Y * \sqrt{XM / T_1 Z}$ -- (1)

Where m is the stem movement of pressure valve, Cv is the valve coefficient, N8 is the constant for engineering units, Fp is the constant for pipeline geometry, M is molecular weight of air, Z the compressibility factor, Expansion factor

$Y = 1 – X / (3*X_K* F_T)$

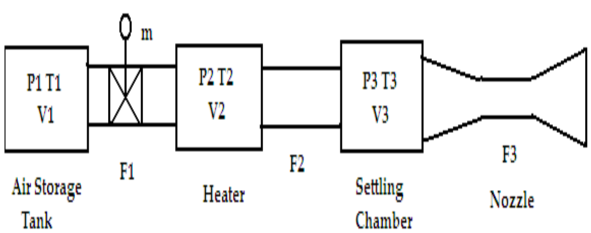


Fig. 2. **Block diagram of the system to be modelled.**

where X_T critical pressure drop ratio factor and F_k ratio of specific heats factor, $X = (P_1 – P_2)/P_1$ where P2 is the upstream pressure and P2 is the downstream pressure of PRV.

Thus,

F1 = f(P1, P2,m) -- (2)

Now from empirical analysis [3], outflow from heater is given by,

$F2 = k_1P2 + k_2P3$ -- (3)

where k1 and k2 are constants and P3 is the settling chamber pressure. Thus,

F2 = f(P2, P3) -- (4)

The mass flow rate through nozzle, F3 [3] is given by

$F3 = kn * P3 / \sqrt{T_3}$ -- (5)

Where kn is the nozzle flow constant and P3 is the settling chamber pressure and T3 is the settling chamber temperature.

Thus,

F3 = f(P3) -- (6)

The continuity equations for three pressure vessels [3], [7] may be written as;

$C_1 * dP_1 /dt= - F_1$ -- (7)

$C_2 * dP_2 /dt= F_2 - F_1$ -- (8)

TABLE I
MODEL PARAMETERS

Parameter	Value
Cv	0.1305
N_8	0.000948
F_P	1
X_T	0.562
M	29
Z	1.077

C3* dP3/dt = F2 - F3 -- (9)

Where,

$C1 = V_1/nRT_1$, $C2 = V_2/nRT_2$, $C3 = V_3/nRT_3$ -- (10)

V2, V2 and V3 are volume of pressure vessel 1, pressure vessel 2 and pressure vessel 3 respectively.The model parameters are given in table 1. We took the pressure in the three vessels, P1, P2,P3 as the state variables, stem movement as the input variable and the settling chamber pressure as the output variable.

III. OPEN LOOP RESPONSE OF THE SYSTEM

The state equations are obtained and the equations of F_1, F_2, F_3, C_1, C_2 and C_3 are obtained by considering the physical and model parameters.With this equations, simulation result of the model in Matlab and obtained the response of settling chamber pressure. The open loop response of the system is shown in fig.(3).

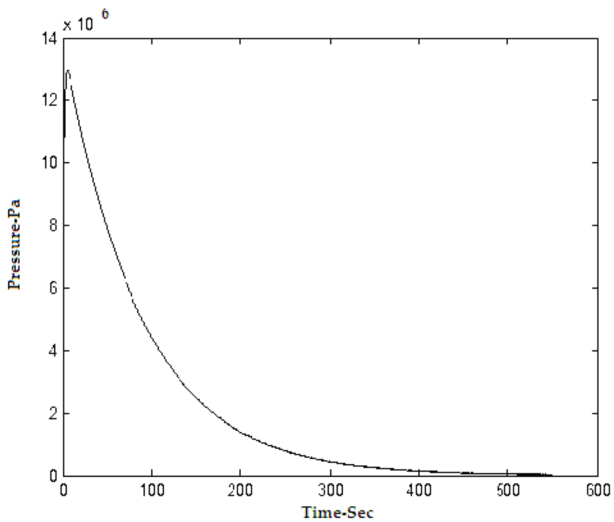


Fig.3. **Response of pressure P3 of nonlinear model.**

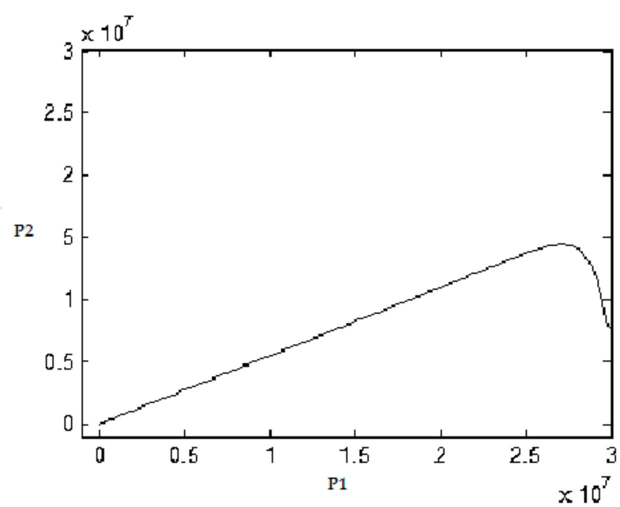


Fig. 4. **Plot of P1 and P2.**

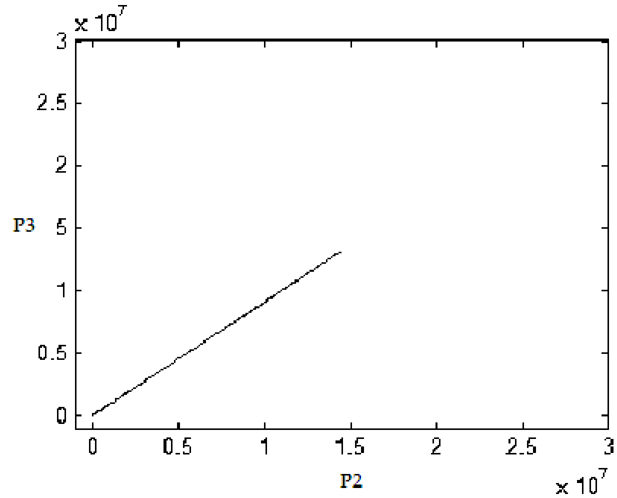


Fig. 5**. Plot of P2 and P3.**

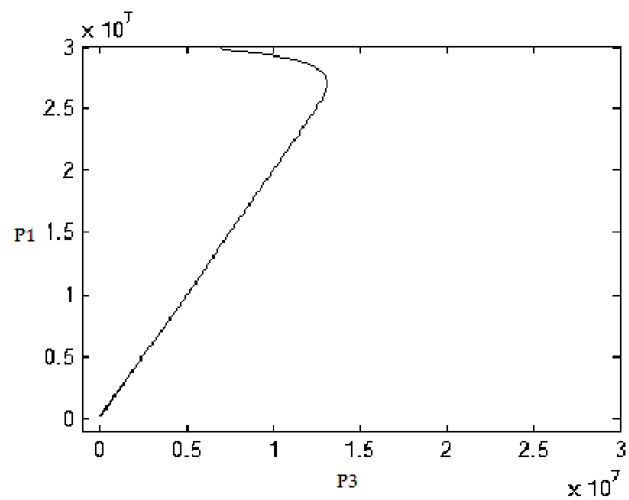


Fig. 6. **Plot of P3 and P1.**

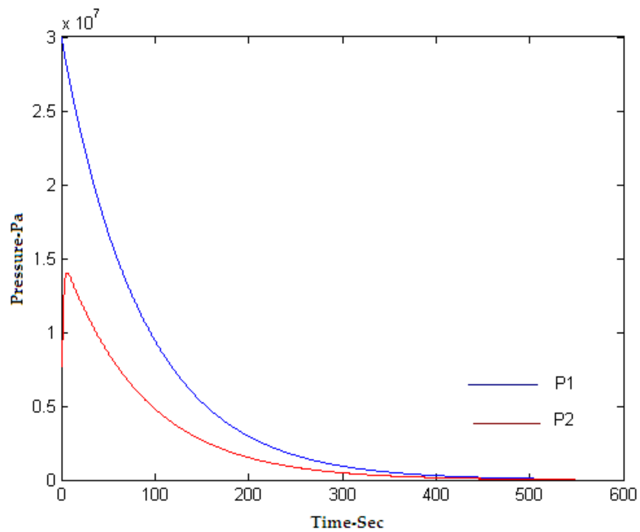


Fig. 7. **Response of pressures P1 and P2.**

IV. DESCRIPTION OF PLANT AND SIMULATION RESULTS WITH PI CONTROLLER

A. System description

1. Pressure Reservoir/Storage tank: This chamber has an input air Flow from the compressor. The Pressure Reservoir stores air at Pressure at 14 bar in system at IIT. It Supplies air Pressure to Settling/Plenum Chamber through Control Valve.

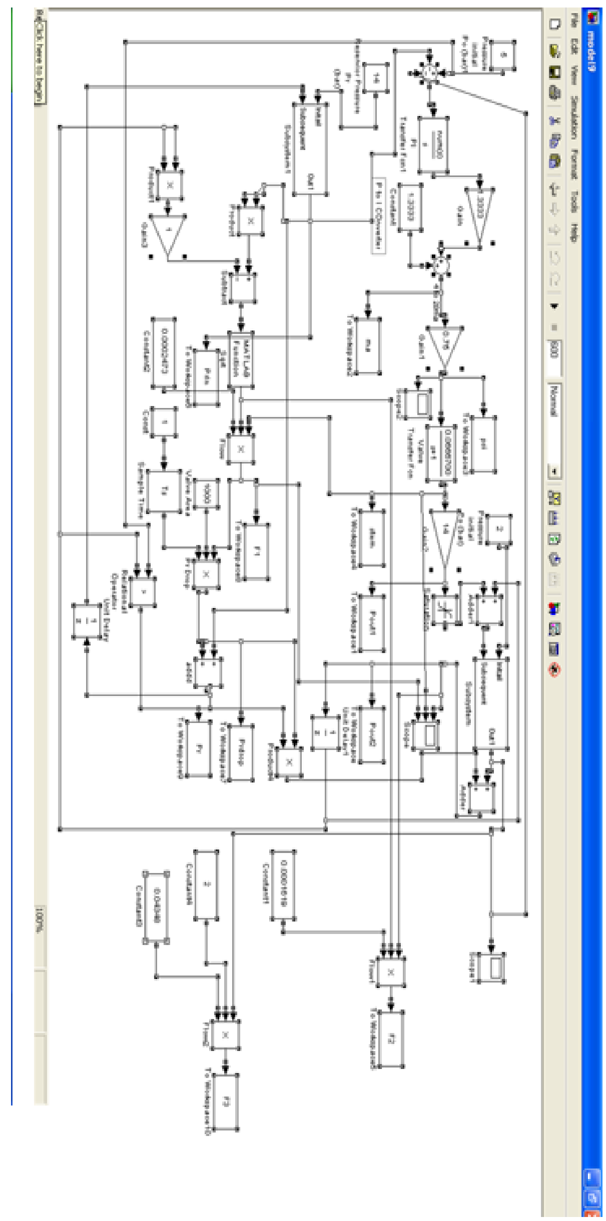
2. Settling/Plenum chamber: This chamber has an input air Flow from the Pressure Reservoir through valve. The minimum pressure that needs to be maintained in this chamber is 2 bar.

As we want the to maintain the constant pressure in the settling chamber say 5 bar as shown in simulation, the adjustments are done accordingly in simulation. The pressure from minimum to maximum that is from 2 to 14 bar is converted to current in the range from 4 to 20 mA by using a P to I converter. So here formula for conversion is $Y=1.33*X+1.33$ -- (11)

B. Valve Transfer Function:

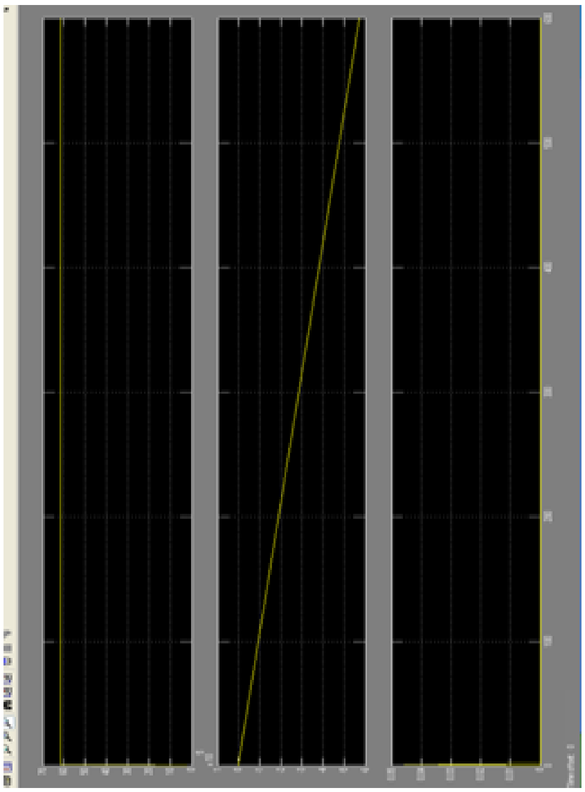
The non linear input output characteristics of PRV is linearized using linearization methods resulting in a first order Transfer function as

$G(s)=0.06667/(S+1)$ -- (12)



Matlab Simulink implementation of Wind Tunnel model in Closed Loop.

V. SIMULATION RESULTS WITH PI CONTROLLER



The figure above shows the closed loop response for the system shown in simulation. Here set value of pressure is 5 bar which is the constant value of pressure that needs to be maintained constant and the pressure in the settling chamber is maintained at 2 bar that we can see in the simulation.

VI. CONCLUSION

In this paper, a PI controller is successfully designed and it is able to control the settling chamber pressure to the required set point. The system is brought to strict feedback form after applying some approximations. The performance of the proposed control law is evaluated through simulations. The Simulated results shows that the settling chamber pressure with the designed controller has no peak overshoot and it settles within 60 sec. Fuzzy and Sliding mode control stratergy can be an alternative to the proposed control stratergy.

VI. REFERENCES

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