Design of Missile Three-Loop Auto-Pilot Pitch Using PID Controller

[1]Rami Ali Abdalla, [2]Muawia Mohamed Ahmed, [3]Eltahir Mohamed Hussein

[1]P.G. Student, Department of Control Engineering, Faculty of Engineering College, El.Neelain University Kh, Sudan
(E-mail id: rami_20236@hotmail.com)
[2]Associate Professor, Department of control Engineering, Faculty of Engineering, El.Neelain University, Kh, Sudan
(E-mail id: muawia15858@hotmail.com)
[3]Associate Professor, Department of Biomedical Engineering, College of Engineering, Sudan University of Since and Technology, Kh, Sudan
(E-mail id: Altahir_33@yahoo.com)

-------------------------------- ● --------------------------------

Abstract: *In This paper aims at designing of three- loop auto-pilot in pitch plane controller based on PID modern control system. The control method is used to determine the gains of the controllers. The Missile data used for the proposed system was of three- loop auto-pilot. The block diagram of the proposed control system with required controller gains is established. a PID controller is introduced in the reduced order model of autopilot system in order to eliminate the steady-state error. A model based PID Trial and Error Tuning Method and Automatic PID Tuning. Were used a numerical example has been considered and the simulation results are obtained through MATLAB software.*

Keywords: *Missile, Three-loop Auto-pilot, Pitch plane, PID Controller.*

-------------------------------- ● --------------------------------

1. Introduction

The missile flight control system is one element of the overall homing loop[2]. Due to the wide parameter variation and stringent performance requirements, missile autopilot design is a challenging task. The traditional method of guaranteeing stability in the presence of aerodynamic parameter variation or uncertainty is the gain scheduling control strategy. Modern air-to-air or surface-to-air missiles need large and uncertain flight envelopes, for which accurate aerodynamic parameters are difficult or extremely expensive to obtain from wind tunnel tests; also, the gain scheduling controllers need more operating points. The control objective for these missiles is to ensure accurate interception, with guaranteed robustness, without sacrificing maneuverability. For this purpose, many advanced modern control theories have been extensively studied by numerous researchers to address this problem[3]. A Guided missile is one which receives steering commands from the guided system to improve its accuracy. Guidance system actually gives command to the auto-pilot to activate the controls to achieve the correction necessary. Autopilot is an automatic control mechanism for keeping the spacecraft in desired flight path. An autopilot in a missile is a closed loop system and it is a minor loop inside the main guidance loop. If the missile carries accelerometer and rate gyros to provide additional feedback into the missile servos to modify the missile motion then the missile control system is usually called an autopilot. When the auto-pilot controls the motion in the pitch and the yaw plane, they are called lateral autopilot. For a symmetrical missile pitch and the yaw autopilots are identical. The process of selecting the controller parameters to meet a given performance specifications is known as controller tuning, and PID controller is one of that Controller Tuning [4].

2. Missile Auto-Pilot Overview

Guided missiles have assumed much importance in recent years. A guided missile is one which receives steering commands from the guided system to improve its accuracy. Guided action for guided missiles may be defined as the process of gathering information concerning the flight of a missile towards a given objective or target and utilizing this information to develop manoeuvring commands to the control system of the missile. Guidance system functions by comparing the actual path of the missile with the desired path and providing commands to the control system which will result in manoeuvring the missile to its desired path. Guidance system actually gives command to the autopilot to activate the controls to achieve the correction necessary. Autopilots are closed loop system and these are minor loops inside the main guidance loop. An autopilot may be defined as the missile control system which modify the missile motion according to accelerometer and / or gyros feedback which provide information about the missile acceleration and body rate respectively. A lateral autopilot receives guidance command from the guided system of the missile to produce desired missile acceleration in lateral planes to follow the guidance path needed to the target. The autopilot responses to guidance system demand by deflecting the control surfaces of the missile for aerodynamic controlled missiles. The deflections in control surfaces produce change in missile angle of incidence. If the incidence angle is changed, the forces acting on the missile body changes and it results in change in missile acceleration. It deals with the modified three-loop lateral missile autopilot design methodology in pitch plane based on its state space model. The three-loop auto-pilot system uses three-loops to feedback information of missile motion to the forward path of the autopilot. One loop is involved with body rate information which is fed back using one rate gyro. The other is the missile acceleration, sensed using accelerometer and provides the main feedback. The autopilot system results in change in missile motion. So, modelling of missile airframe dynamics is an important part of configuring an autopilot system. Missile dynamics is of non linear type. For configuring missile dynamics in transfer function form the missile airframes are trimmed and then linearized[1]. The following block diagrams (Fig. 1 represents the transfer function model of flight path rate demand three loop auto-pilot in pitch plane)[5].

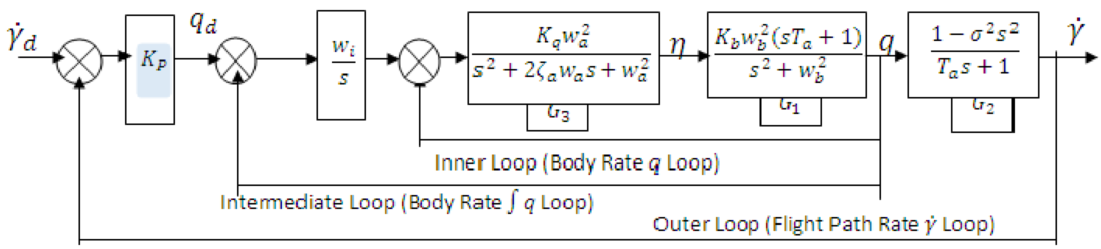

Fig. 1 Conventional Three-Loop Auto-pilot Configuration (Transfer Function Model)

The open loop model i.e. the cascaded combination $-\frac{W_i}{S}$ G1G2G3 of fig.1 can be converted to the corresponding state space model given by $X = Ax = Bu$ & $y = Cx$ (discussed in the next section) and the conventional three-loop configuration can be converted to an equivalent state space model.

Where γ *is flight path rate;q is pitch rate,* w_a *is natural frequency of Actuator,* ζ_a *is damping ratio of actuator,* K_P, K_q, K_b *are the control gains,* w_b *is weather cock frequency,* T_a *is the incidence lag of the air frame,* η *is Elevator deflection;* σ *is aquantity whoose invese determines the locations of non–minimum phase zeros,* W_i *integrator gain.*

3. Mathematical Model of Three-Loop Autopilot from the Conventional One

A. State-Space of Two Loop Autopilot

The open loop model of two loop autopilot (Fig. 1)

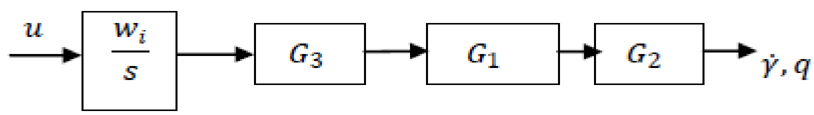

Fig. 2 Four State Variables

can be converted to state variable form based on the following four state variables: $x1=\gamma$ *Flight path rate demand* ; $x2=q$ *pitch rate* ; $x3= \eta$ *elevator deflection* ; $x4=\eta$ (*rate of chance of elevator deflection* Out of them $x1$ *and* $x\mathbf{2}$ have been considered to be as outputs. Thus two-loop autopilot model is a SIMO (single input – multiple outputs) system. Such that the A, B & C matrices become (taken from **[5]**).

$$A = \begin{bmatrix} -\frac{1}{T_a} & -\frac{K_b \sigma^2 w_b^2}{T_a} & \frac{(1+\sigma^2 w_b^2)}{T_a} & -K_b \sigma^2 w_b^2 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ -\frac{(1+w_b^2 T_a^2)}{T_a(1+\sigma^2 w_b^2)} & \frac{K_b W_b^2 T_a (1-\sigma^2/T_a^2)}{(1+\sigma^2 w_b^2)} & \frac{1}{T_a} & 0 & 0 \\ 0 & -W_a^2 & 0 & -2\zeta_a W_a & K_q W_a^2 W_i \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}; B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \qquad (1a)$$

$$and\ C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \qquad (1b)$$

Now the state space equivalent model of conventional three-loop auto-pilot (Fig.1) can be represented by the state space equation given by (1a & 1b).

Numerical Values

The following numerical data for a class of guided missile have been considered for MATLAB simulation [5].

$$A = \begin{bmatrix} -2.77 & 1.1860 & 2.8894 & 0.4269 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ -50.6161 & -508.388 & 2.77 & 0 & 0 \\ 0 & -32400 & 0 & -216.0 & -85613.76 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} u \qquad (2a)$$

$$Y = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} \qquad (2b)$$

As the analysis and synthesis of higher order systems are difficult and generally not desirable on economic and computational consideration, the reduced order model of the original autopilot system is obtained so that the obtained reduce order system maintains the characteristics of the original system. The reduced order model of the original autopilot system is obtained through Matlab by function **dcgainmr(sys,ord)** .

The resulting:

$$A = [1.494\mathrm{e} - 15][X1] + [0.9341]U \qquad (3a)$$

$y = [30.$

B. Transfer Function of Two Loop Autopilot

Dynamical stability analysis is performed in the following section using Matlab software for examining the roots of the characteristic equation. The function ss is used for creating state-space model within the Matlab enviroment, which takes the model data as input and produces ss object that store this data in a single Matlab variable. Transfer function is by matlab in the following manner: H=tf(system). The Reduced-order transfer function as obtained by Matlab is

$$\frac{\dot{\gamma}}{\gamma_d} = \frac{28.06}{s - 1.494e - 15} \qquad (4)$$

The resulting closed-loop step response is shown Figure 3.

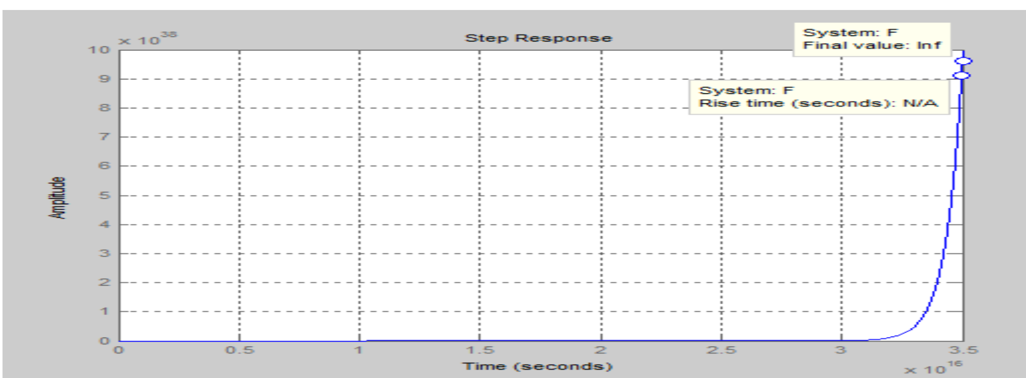

Fig. 3 Step response of original Three loop autopilot

Proportional-Integral-Derivative (PID) Control

PID control logic is widely used in the process control industry. PID controllers have traditionally been chosen by control system engineers due to their flexibility and reliability [6]. A PID controller has proportional, integral and derivative terms that can be represented in transfer function form as

$$K(S) = K_p + \frac{K_i}{S} + K_d S \qquad (5)$$

Where K_p represents the proportional gain, K_i represents the integral gain, and K_d represents the derivative gain, respectively. By tuning these PID controller gains, the controller can provide control action designed for specific process requirements [6]The proportional term drives a change to the output that is proportional to the current error. This proportional term is concerned with the current state of the process variable. The integral term (K_i) is proportional to both the magnitude of the error and the duration of the error. It (when added to the proportional term) accelerates the movement of the process Ktowards the set point and often eliminates the residual steady-state error that may occur with a proportional only controller. The rate of change of the process error is calculated by determining the differential slope of the error over time (i.e., its first derivative with respect to time). This rate of change in the error is multiplied by the derivative gain (K_d) [6].

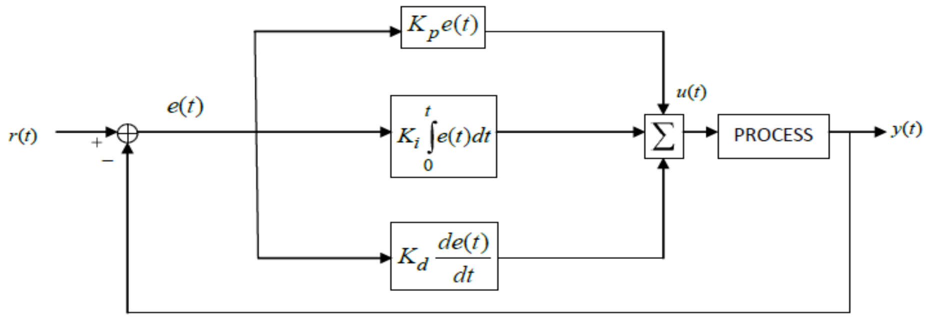

Fig. 4 PID control logic.

4. Results and Discussions

A. Trial and Error Tuning Method

If the system must remain online, one tuning method is to first set Ki and Kd values to zero. Increase the Kp until the output of the loop oscillates, then the Kp should be set to approximately half of that value for a "quarter amplitude decay" type response. Then increase Ki until any offset is corrected in sufficient time for the process. However, too much Ki will cause instability. Finally, increase Kd, if required, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much Kd will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the set point more quickly; however, some systems cannot accept overshoot, in which case an over-damped closed-loop system is required, which will require a Kp setting significantly less than half that of the Kp setting that was causing oscillation [7].

- **PI control**

In proportional and integrative controller mode, the transfer function bellow was produced and added to system, reminding that adding P or I may improves some required response and but still cause and undesired response[4].

$$G_c(S) = K_P + \frac{K_I}{S} \quad (6)$$

This transfer function is a PID compensator with K_i = 0.17728 and K_p = 0.10909.The resulting closed-loop step response is shown Figure 5.

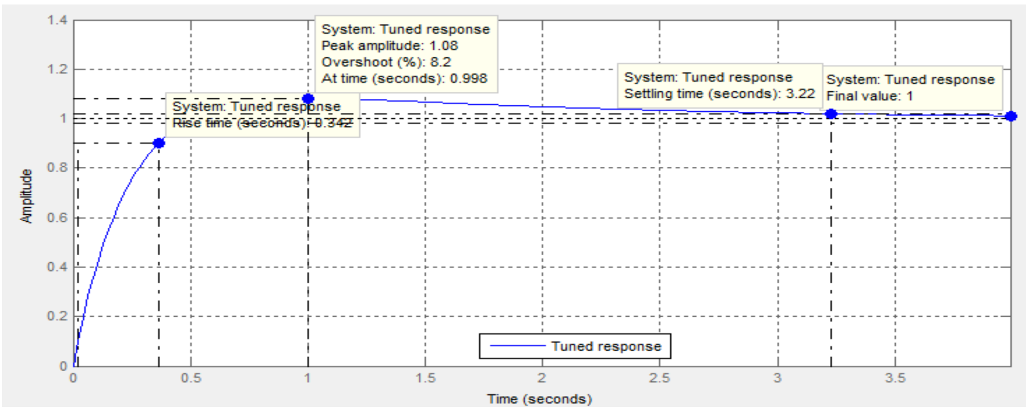

Fig. 5 Step response of reduced order model of Three-loop auto-pilot with PI controller.

B. Automatic PID Tuning

MATLAB provides tools for automatically choosing optimal PID gains which makes the trial and error process described above unnecessary. You can access the tuning algorithm directly using pidtune or through a nice graphical user interface (GUI) using pidtool. The MATLAB automated tuning algorithm chooses PID gains to balance performance (response time, bandwidth) and robustness (stability margins). By default the algorthm designs for a 60 degree phase margin.[8] This transfer function is a PID compensator with K_i = 0.36385, K_p = 0.35637 and K_d=0.0036385 .The resulting closed-loop step response is shown Figure 6.

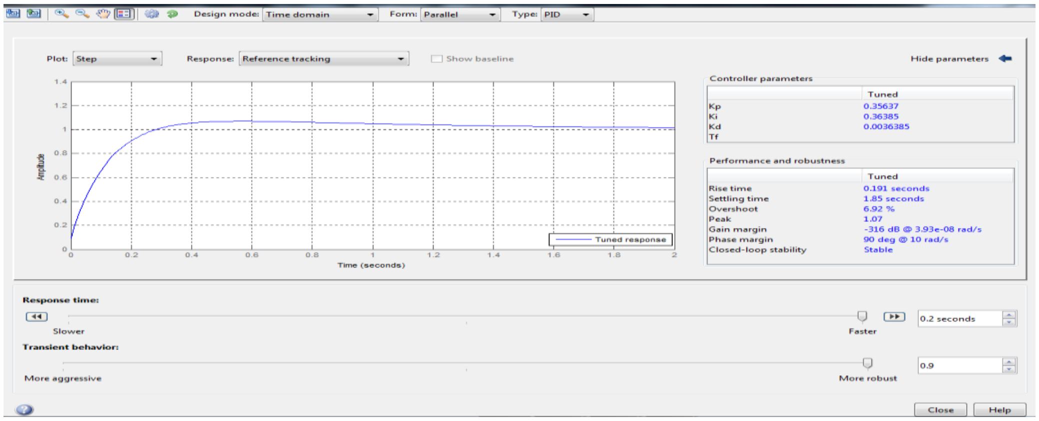

Fig. 6 Step response of reduced order model of Three-loop autopilot with Automatic PID Tuning**.**

5. Conclusion

In this paper, the steady state performance of the flight path rate demand of the three-loop Auto-pilot system has been improved. It has been shown that the steady state response of reduced order autopilot system obtained by matlab is exactly matching with that of the original autopilot system .The PI controller introduced in the reduced order model of autopilot system eliminates the system static error and showed overshoot value around 6.92, with settling time value of 1. 85 s and rise time value of 0.191 seconds.

REFERENCES

[1] Jyoti Prasad Singha Thakur, Amit Mukhopadhyay, 2013, "A Simple Design Approach In Yaw Plane For Two Loop Lateral Autopilots", International Journal of Innovative Research in Science, Engineering and Technology.

[2] Paul B. Jackson, 2010, "Overview of Missile Flight Control Systems", Johns Hopkins Apl Technical Digest.

[3] He Shao-ming, Lin De-fu, 2014", Missile two-loop acceleration autopilot design based on L1 adaptive output feedback control", Intl J. of Aeronautical & Space Sci.

[4] A. Chowdhury and S. Das, 2013, "Analysis and Design of Missile Two Loop Autopilot", Advance in Electronic and Electric Engineering.

[5] Parijat Bhowmick, Prof. Gourhari Das, 2012, " Modified Design of Three Loop Lateral Missile Autopilot based on LQR and Reduced Order Observer (DGO)", International Journal of Engineering Research and Development.

[6] Manoj Gogoi, 2007, " Proportional-Integral-Derivative (PID) Controller Design For Robust Stability Of Arbitrary Order Plants With Time-Delay And Additive Uncertainty", Bachelor of Technology, B.P.U.T.

[7] http://en.wikipedia.org/wiki/PID_controller.

[8] http://partner50.mydomainadvisor.com/search.php?pr=vmn&id=mystarttb&v=5_4&ent=dn_5106&q=ctms.engin.umich.edu/CTMS/index.php