UNIVERSITY OF JORDAN
Mechanical Engineering Department
Control lab

Tow Rotor Aero-dynamical System

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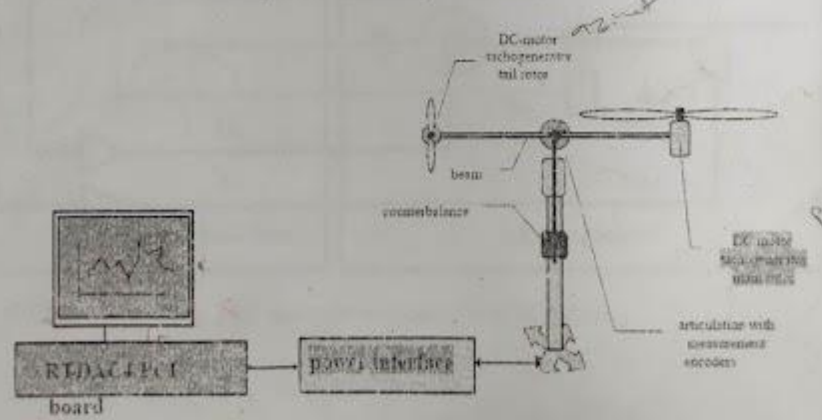
Objectives

1-to stady Twin Rotor System in two cases:
 -One degree of freedom (1-DOF) with azimuth and pitch model.
 -Two degree of freedom (2-DOF) cross coupled model.
2-To study the effect of applying different type of controllers on TRAS system.

Introduction

Two Rotor Aero-dynamical System (TRAS) is a laboratory set-up designed for control experiments. In certain aspects its behaviour resembles that of a helicopter. From the control point of view it exemplifies a high order nonlinear MIMO system with significant cross-couplings. The system is controlled from a PC. Therefore it is delivered with hardware and software which can be easily mounted and installed in a laboratory. You obtain the mechanical unit with power supply and interface to a PC and the dedicated RT-DAC/PCI I/O board configured in the Xilinx® technology. The software operates in real-time under MS Windows® XP using MATLAB® R2008a/b, R2009a/b and R2010a/b with RTW and RTWT toolboxes.
Control experiments are programmed and executed in real-time in the MATLAB/Simulink environment. Thus it is strongly recommended to a user to be familiar with the RTW and RTWT toolboxes. One has to know how to use the attached models and how to create his own models.
The approach to control problems corresponding to the TRAS proposed in this manual involves some theoretical knowledge of laws of physics and some heuristic dependencies difficult to be expressed in analytical form.

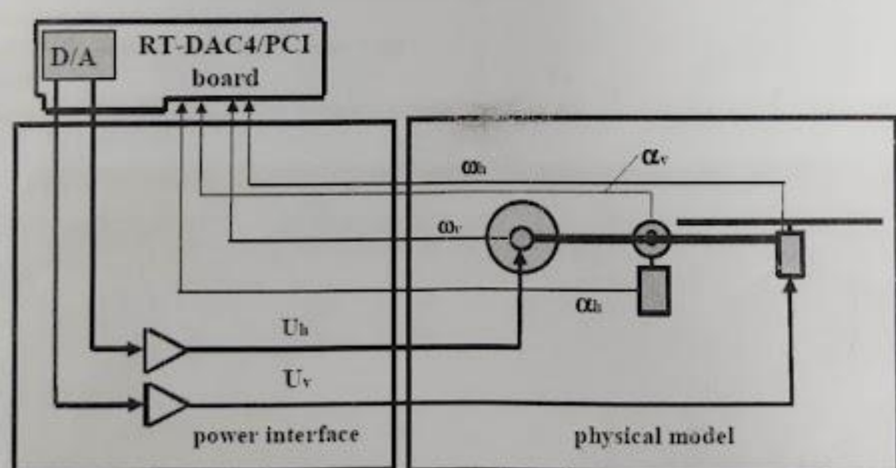


Fig(1): The laboratory set-up: helicopter-like system.

A schematic diagram of the laboratory set-up is shown in Fig (1). The TRAS consists of a beam pivoted on its base in such a way that it can rotate freely both in the horizontal and vertical planes. At both ends of the beam there are rotors (the main and tail rotors) driven by DC motors. A counterbalance arm with a weight at its end is fixed to the beam at the pivot. The state of the beam is described by four process variables: horizontal and vertical angles measured by position sensors fitted at the pivot, and two corresponding angular velocities. Two additional state variables are the angular velocities of the rotors, measured by tacho-generators coupled with the driving DC motors.

In a casual helicopter the aerodynamic force is controlled by changing the angle of attack of the rotors. The laboratory set-up from Fig (1) is so constructed that the angle of attack is fixed. The aerodynamic force is controlled by varying the speed of rotors. Therefore, the control inputs are the supply voltages of the DC motors. A change in the voltage value results in a change of the rotation speed of the propeller which results in a change of the corresponding position of the beam. Significant cross-couplings are observed between the actions of the rotors: each rotor influences both position angles. Designing of stabilizing controllers for such a system is based on decoupling. For a decoupled system an independent control input can be applied for each coordinate of the system.

An IBM-PC compatible computer can be used for real-time control of TRAS. The computer must be supplied with an interface board (RT-DAC/PCI). Fig(2) shows details of the hardware configuration of the control system for TRAS.



Fig(2): Hardware configuration of TRAS.

The control software for TRAS is included in the *TRAS toolbox*. This toolbox uses the RTWT and RTW toolboxes from MATLAB.

TRAS Toolbox is a collection of M-functions, MDL-models and C-code MEX-files that extends the MATLAB environment in order to solve TRAS modelling, design and control problems. The integrated software supports all phases of a control system development:

- on-line process identification,
- control system modelling, design and simulation,
- real-time implementation of control algorithms.

TRAS Toolbox is intended to provide a user with a variety of software tools enabling:

- on-line information flow between the process and the MATLAB environment,
- real-time control experiments using demo algorithms,
- development, simulation and application of user-defined control algorithms.

TRAS Control Window

Starting and testing procedures

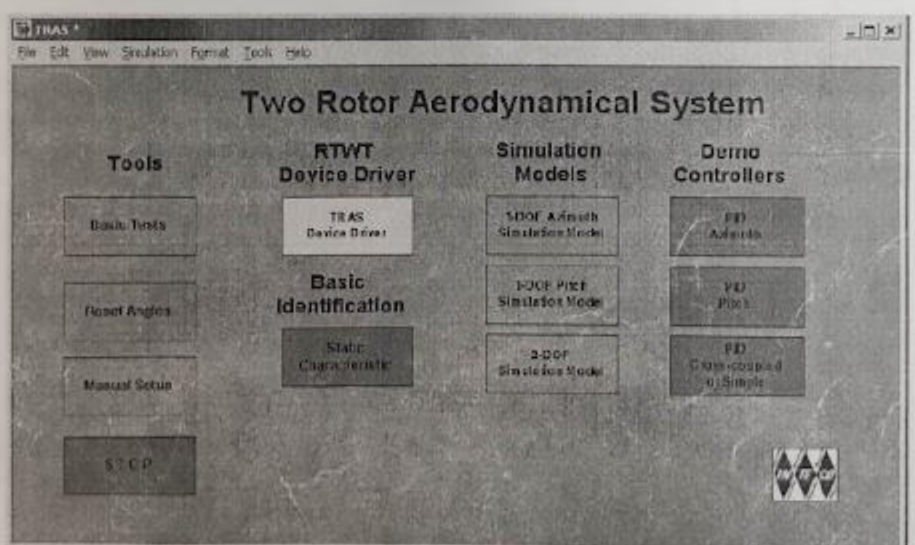
The TRAS system is an "open" type. It means that a user can design and solve any TRAS problem on the basis of the attached hardware and software. The software includes device drivers compatible with RTWT toolbox. It is assumed that a user is familiarized with MATLAB tools especially with RTWT toolbox. Therefore we do not include the detailed description of this tool.

The user has a rapid access to all basic functions of the TRAS System from the *TRAS Control Window*. It includes: identification, drivers, simulation model and application examples.

In the Matlab command window type

tras

and then the *TRAS Control Window* opens (see Fig(3))



Fig(3): TRAS Control Window

TRAS Control Window contains: testing tools, drivers, models and demo applications. The user has a rapid access to all basic functions of the TRAS control system from *TRAS Control Window*.
TRAS Control Window shown in Fig(3) contains four groups of the menu items:

- Tools - Basic Test, Manual Setup, Reset Encoders and Stop Experiment,
- Drivers - RTWT Device Driver,
- Simulation Models: Pitch , Azimuth and 2-DOF model,
- Identification - Steady State Characteristics,
- Demo Controllers – PID azimuth, PID pitch and cross-coupled PID controller.

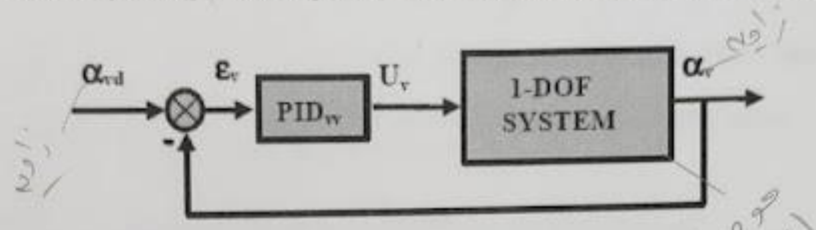
Controllers and real-time experiments

In the following section we propose three PID controllers. It is possible to tune the parameters of the controllers without analytical design. Such approach to the control problem seems to be reasonable if a well identified model of TRAS is not available. The effectiveness of the PID controllers discussed here is illustrated by control experiments.

PID controllers
One degree of freedom (1-DOF) control problem is the following. Design a controller that will stabilise the system, or make it follow a desired trajectory in one plane (one degree of freedom) while motion in the other plane is blocked mechanically or being controlled by another controller.
If TRAS is free to move in both axes we refer to the control as two degree of freedom (2- DOF). The four PID controllers for TRAS: PID_{vv}, PID_{vh}, PID_{hv} and PID_{hh} (h-horizontal (azimuth), v-vertical (pitch)) are considered. The subscripts indicates the source-sink relation for the controller. Each control signal (U_v and U_h) is the sum of two controller outputs. For example, vertical control denoted later as U_v is the sum of two output signals: PID_{vv} and PID_{hv}. The internal structure of each PID controller is shown in Fig. 5.15b. There are three parameters to be set for every controller: K_p, K_i and K_d. The TRAS control in the vertical and horizontal planes requires setting altogether 12 (3×4) controller parameters. Saturation blocks introduce four additional I_{sat} parameters: I_{vvsat}, I_{vhsat}, I_{hhsat} and I_{hvsat}, which are the limits of absolute values of the integrals of errors, and two: U_{hmax} and U_{vmax} parameters, which are the limits of absolute value of controls. These 18 (12+4+2) parameters have their default values.

Part1: Vertical 1-DOF control

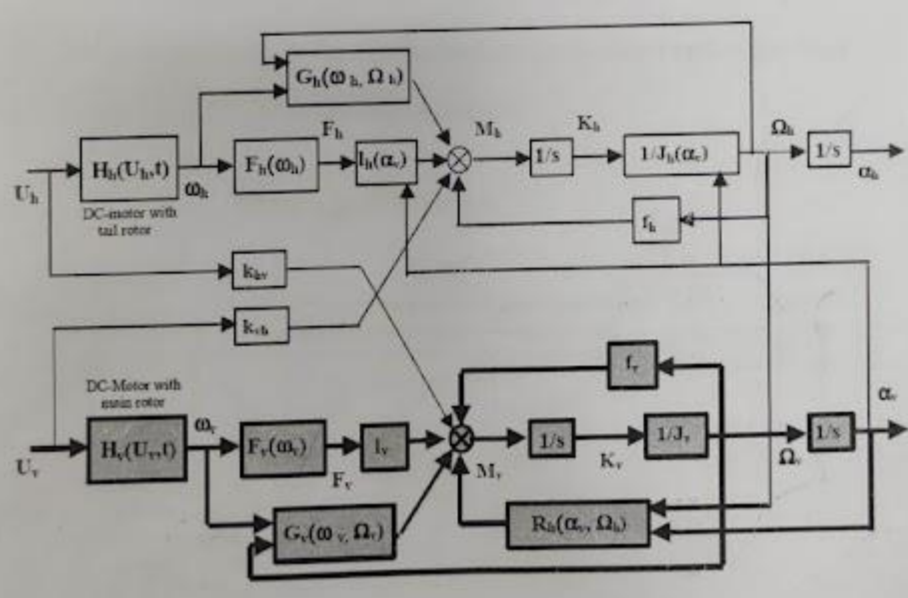
At the beginning we restrict our control objective to stabilising the system in the vertical plane only. We reduce the original system to the 1-DOF system by mechanically fixing (using the included clamp) its freedom to move in the horizontal plane. A corresponding block diagram of the PID control system is shown in Fig(4)



α_{vd} - desired pitch

Fig(4): 1-DOF pitch control system

The block diagram below shows the system in a more detailed form (Fig(5)). Notice, that only the vertical part of the control system is considered.



Fig(5) : The block diagram 1-DOF system (vertical plane)

Real-time 1-DOF pitch control experiment

Fix TRAS in the horizontal plane using the special plastic clamps delivered with TRAS. Set it in the neutral vertical position and wait until the all oscillations are damped.

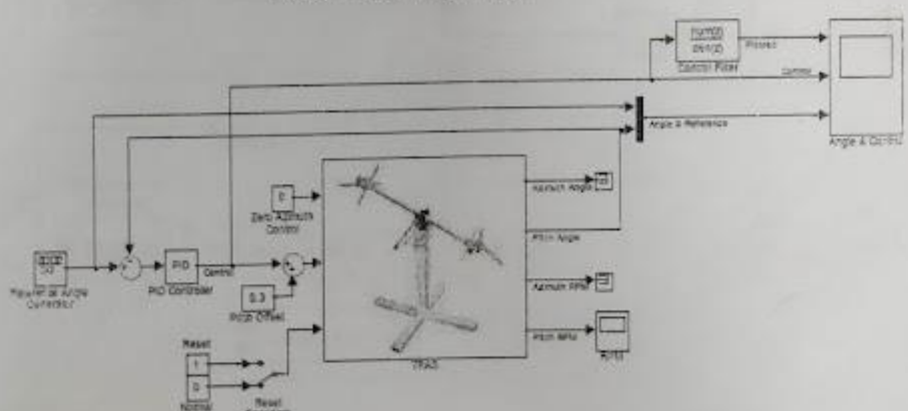
1-Set it in the zero position and click on the *Reset Encoders* block in *Tras Control Window*.
2-Click the *PID Pitch controller* button and the model shown in Fig(6) opens.
3- Set all PID controller coefficients as follows:

Table1

number	K_p	K_i	K_d
1	0.6784*1.2	0.4415*0.8	0
2	0.6784*1.2	0	1.31196*0.4
3	0.6784*2	0	1.31196*0.4
4	0.6784*1.2	0.4415	1.31196*0.4
5	0.6784*1.2	0.4415*0.8	1.31196*0.4

4- Set saturation of the integral part of the controller to 1.43
5-Set the reference signal as square wave with 0.2[rad] amplitude and 1/40 [Hz] frequency
6- Build the model and click on the *Simulation/Connect to target* option and *Start real-time code* option.
7-plot the result from 1 to 5 and discuses the result.

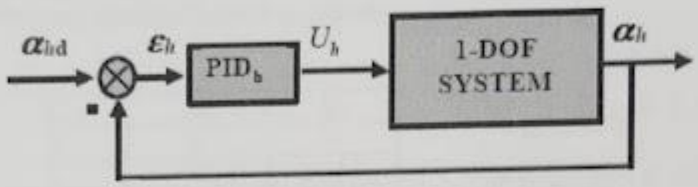
TRAS 1-DOF PID Pitch



Fig(6): Real-time model for the pitch control

Part2: Horizontal 1-DOF control

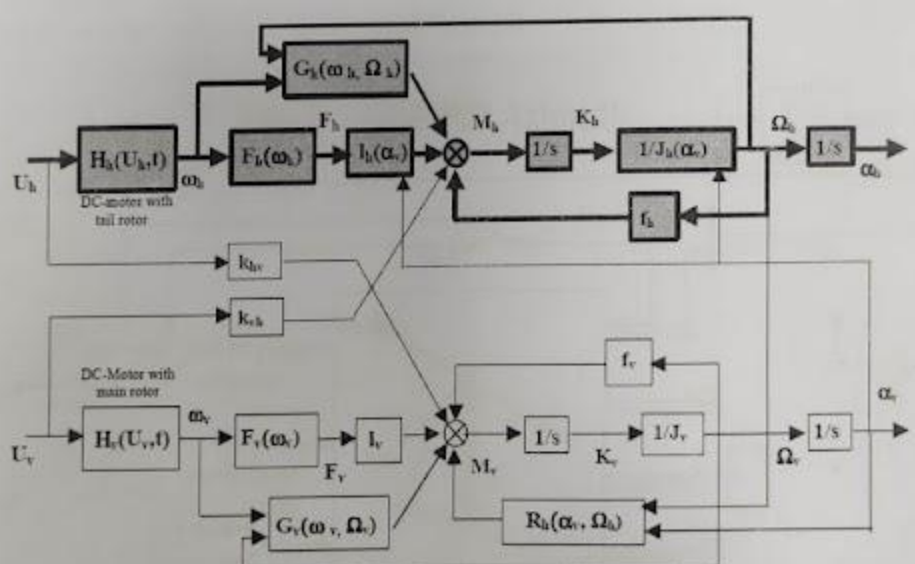
In the next experiment we apply stabilising PID controller in the horizontal plane. We block the system in one axis so that it cannot move in the vertical plane (using the included fixing rectangle).. A corresponding block diagram of the control system is shown in Fig(7) and in a more detailed form in Fig(8).



α_{hd} -desired azimuth

Fig(7): 1-DOF control closed-loop system (azimuth stabilisation)

Notice that only the 'horizontal' part of the control system is considered.



Fig(8): The block diagram of 1-DOF system (horizontal plane)

Real-time 1-DOF azimuth control experiment

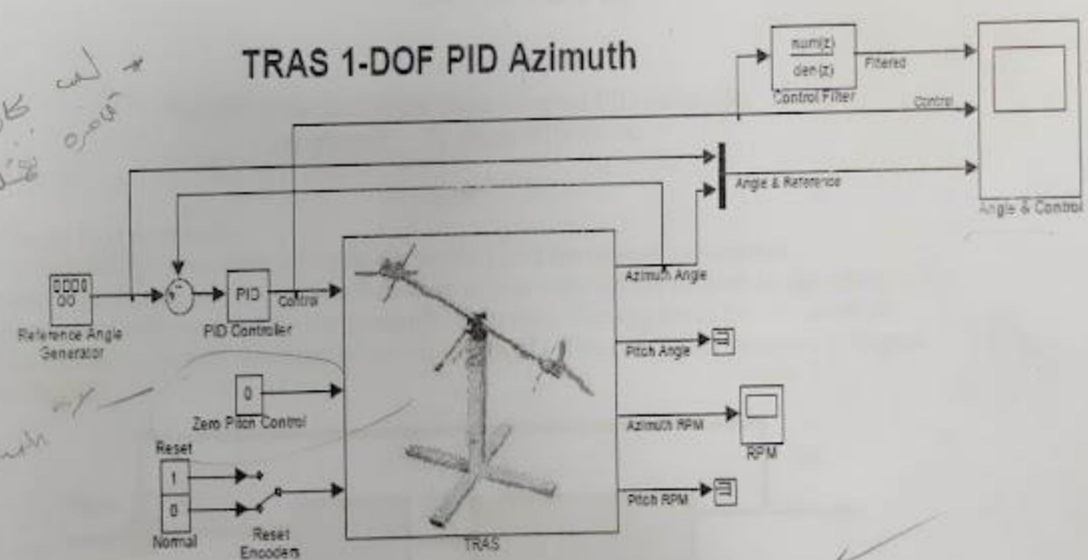
Fix TRAS in the vertical plane using the special fixing rectangle delivered with TRAS.

1-Set it in the zero position and click on the *Reset Encoders* block in *Tras Control Window*.
2-Click *PID Azimuth controller* and the model shown in Fig(9) opens.
3-Set all PID controller coefficients as follows:

Table2

number	K_p	K_i	K_d
1	3	0	0
2	3	0	5.188
3	5	0	5.188
4	7	0	5.188
5	5	0.2	5.188

4- Set saturation of the integral part of the controller to 1.0
5-Set the reference signal as square wave with 0.5 [rad] amplitude and 1/20 [Hz] frequency
6- Build the model and click on the *Simulation/Connect to target* and *Start real-time code* options.
7-plot the result from 1to 5 and discuses the result.

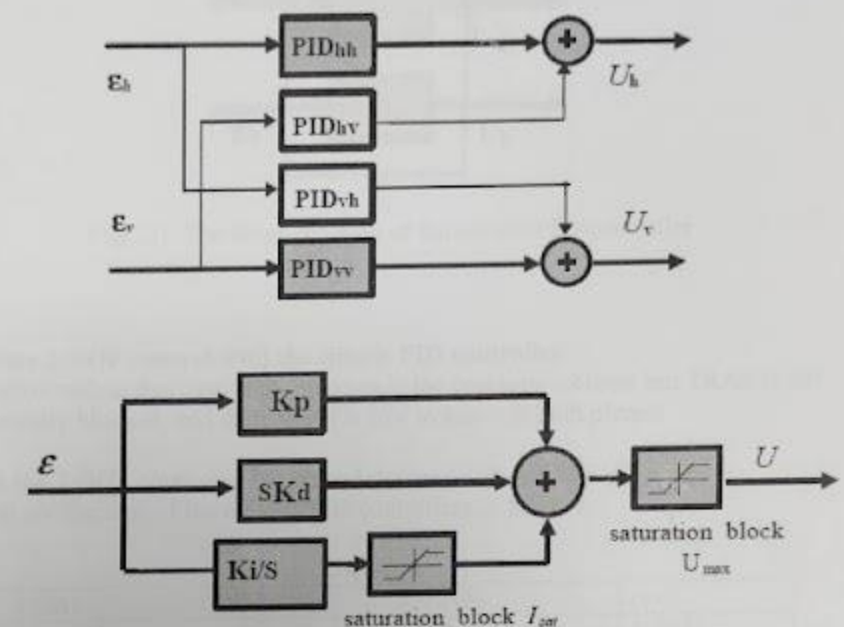


Fig(9): Real-time model for the PID azimuth control

Part 3: 2-DOF PID controller

The structure of the cross-coupled multivariable PID controller is shown in Fig(10).

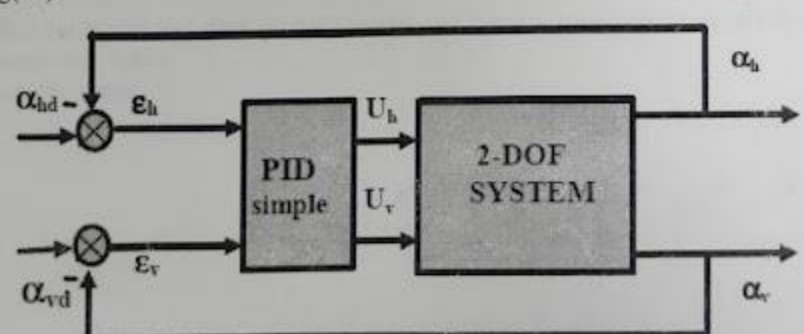
a) b)



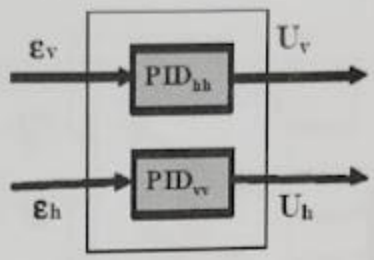
Fig(10): Structure of the cross-coupled PID controller
a) general b) single PID block

Simple PID controller

The simple PID controller controls the vertical and horizontal movements separately. In this control system influence of one rotor on the motion in the other plane is not compensated by the controller structure. The system is not de-coupled. The control system of this kind is shown in Fig(11). The controller structure is shown in Fig(12).



Fig(11): The block diagram of 2-DOF control system with a simple PID-controller



Fig(12): The block diagram of the simple PID-controller

Real-time 2-DOF control with the simple PID controller

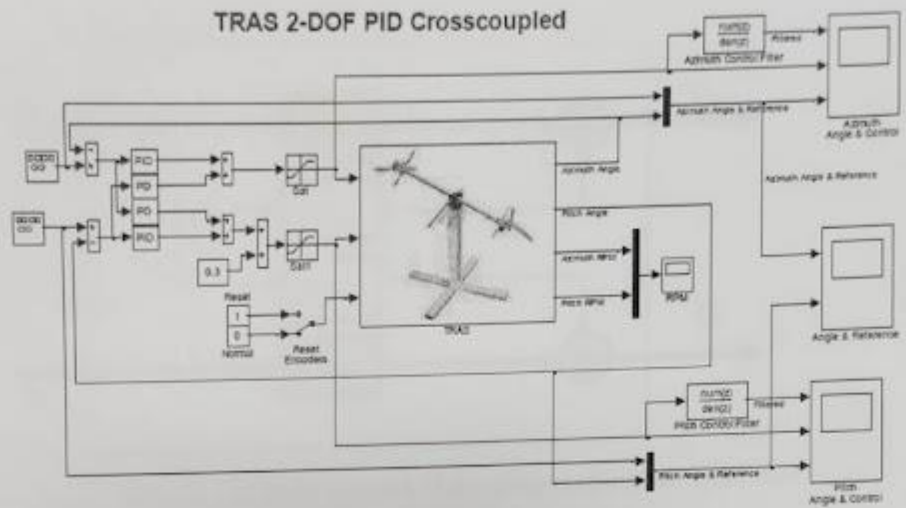
The control task in this case is the same as in the previous sections but TRAS is not mechanically blocked, and therefore it is free to move in both planes.

1-Click the *2-DOF controller* button and the model shown in Fig(13) opens.
2-Set all coefficients of the crossed PID controllers as follows:

Table3:

	(hh)	(hv)	(vh)	(vv)
K_p	3.1352	0	0	1.2627
K_i	0	0	0	1.4014
K_d	2.2094*2	0	0	1.2074

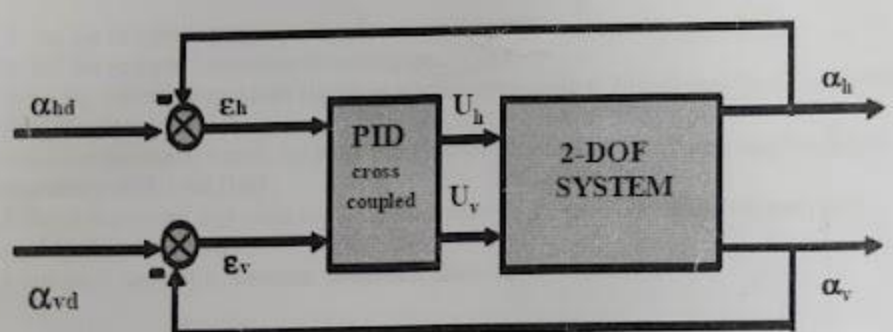
3- Set the integral saturation in azimuth part to 1.0
4- Set the integral saturation in pitch part to 1.0
5-Set the reference azimuth signal as square wave with 0.2 [rad] amplitude and 1/40 [Hz] frequency
6-Set the reference signal for apitch as sinusoidal wave with 0.2[rad] amplitude and frequency with 1/40 [Hz] .
7-Set the reference azimuth signal as square wave with 0.2 [rad] amplitude and 1/40 [Hz] frequency.
8- Build the model and click on the *Simulation/Connect to target* option and *Start real-time code* option.
9- show the result.



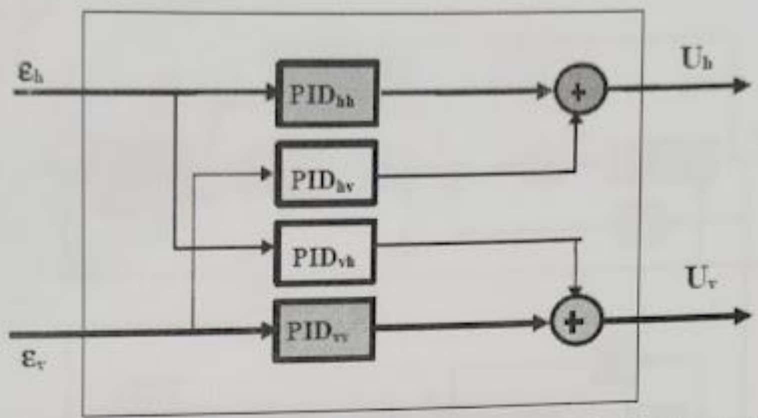
Fig(13): Real-time model of the 2-DOF control task

Cross-coupled PID controller

The cross-coupled PID controller steers the system in the pitch and azimuth planes. In this control system the influence of one rotor on the motion in the other plane can be compensated by the cross-coupled structure of the controller. The control system is shown in Fig(14). The cross-coupled PID controller structure is shown in Fig(15).



Fig(14): The block diagram of the 2-DOF control system with the cross-coupled PIDcontroller



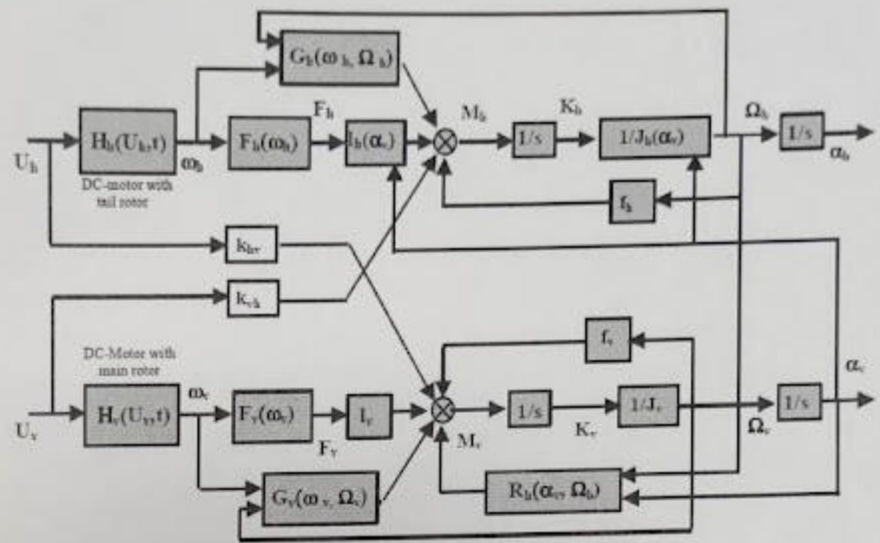
Fig(15): The block diagram of the cross-coupled PID controller

1-Click the *2-DOF controller* button and the model shown in Fig(13) opens.
2-Set the coefficients of the crossed PID controllers as follows:

Table4

	(hh)	(hv)	(vh)	(vv)
K_p	3.2465	-0.9334	-0.0363	0.4978
K_i	0.0367	0	0	0.4392
K_d	2.152*2	-0.7845	-0.0223	0.4464*2

3- Set the integral saturation in azimuth part to 1.0
4- Set the integral saturation in pitch part to 1.0
5-Set the reference azimuth signal as square wave with 0.2 [rad] amplitude and 1/40 [Hz] frequency
6-Set the reference signal for apitch as sinusoidal wave with 0.2[rad] amplitude and frequency with 1/40 [Hz] .
7-Build the model and click on the *Simulation/Connect to target* option and *Start real-time code* option.
8-compure the result between table3 and table 4.



α_h is horizontal position (azimuth position) of TRAS beam [rad],
Ω_h is angular velocity (azimuth velocity) of TRAS beam [rad/s],
U_h is horizontal DC-motor PWM control input,
ω_h is rotational speed of tail rotor [rad/s] - nonlinear function
$\omega_h = H_h(U_h t)$ [rad/s],
F_h is aerodynamic force from tail rotor - nonlinear function $F_h = F_h(w_h)$ [N],
l_h is effective arm of aerodynamic force from tail rotor $l_h = l_h(a_v)$ [m],
J_h is nonlinear function of moment of inertia with respect to vertical axis,
$J_h = J_h(a_v)$ [kg m2],
M_h is horizontal turning torque [Nm],
K_h is horizontal angular momentum [Nms],
f_h is oment of friction force in vertical axis [Nm],
α_v is vertical position (pitch position) of TRAS beam [rad],
Ω_v is angular velocity (pitch velocity) of TRAS beam [rad/s],
U_v is vertical DC-motor PWM voltage control input,
ω_v is rotational speed of main rotor - nonlinear function $\omega_v = H_v(U_v t)$ [rad/s],
F_v is aerodynamic force from main rotor - nonlinear function $F_v = F_v(\omega_v)$ [N],
l_v is arm of aerodynamic force from main rotor [m],
J_v is moment of inertia with respect to horizontal axis [kg m2],