Performance analysis of PID and LQG control algorithms for Antenna Position Control system.

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***Abstract*—Ground station antennas find their application in communication with satellites. An antenna communicates with the spacecraft by sending command signals and receiving the data from the spacecraft. Antenna dish rotates with respect to elevation axis and whole antenna structure rotates on circular track which is an azimuth axis [1]. This paper discusses performance evaluation of two control algorithms on Antenna Control Servo System namely conventional PID algorithm and model based LQG algorithm. Power Pmac controller along with Power Pmac IDE and Pmac Servo Analyzer are used for implementing control algorithms. Results have been tested for single motor single drive position control system. Hardware results for step and ramp signals for azimuth position have been evaluated. Paper concludes with inferences drawn from the designed control algorithm.**

Keywords*—*System Identification, Step test, Ramp test,Antenna Control systems,Power Pmac,Servo Analyser,PID ,LQG.

I. INTRODUCTION

A position control system basically consists of position sensing module and error correction module. The aim to; set the actual value from the position encoder (18 bit) to match with desired position value, thus reducing the error. For positioning control standard servo PID algorithm and LQG control algorithm have been implemented in Power Pmac controller. Antenna servo control system with monopulse tracking has been described briefly in section II. Section III explains PID control algorithm. Section IV simulation of PID algorithm on antenna position control system. Section V is about introduction to power Pmac controller. .Section VI describes real-time results of developed PID algorithm. Section VII concludes the paper. References and acknowledgements are provided in Section VIII and Section IX respectively.

II. ANTENNA CONTROL SERVO SYSTEM

For assurance of continuous tracking during earth's rotation antenna dish rotates with respect to two control axis.

The horizontal control axis is called elevation and vertical axis is azimuth. Antenna control servo systems (ACSS) consists of two parts situated in pedestal room. The antenna control unit (ACU) is a part of ACSS which consists of controller responsible for position control. Controller used is Power Pmac controller.[1] Antenna drive unit (ADU) is a part of ACSS which consists of electrical driving components like drives ,motors, gears etc.[3]

Figure (1) shows antenna control systems. The primary operator interface for the Antenna control servo system is the Remote Antenna Console (RAC) located in the TTC Control Room at a distance from the Antenna Control Unit (ACU) which provides remote control of ACU. The Remote Antenna Console (RAC) communicates with the Antenna Control Unit (ACU) over OFC (Optical Fiber Cable) Interface for 100 to 300 m distance.

ACU is responsible for closing the position loop, reading the position sensors and commanding the antenna azimuth/elevation drives (ADU). In order to remove the effect of backlash in gears ADU has been provided with counter torque arrangement. The position loop is built with appropriate inner loops (rate loop and current loops) such that the equal-and-opposite counter-torque-bias is added appropriately at the rate loop input and both motors feedback taken in the loops. ACU provides antenna control functions for remote operations from motion and control system through RAC.

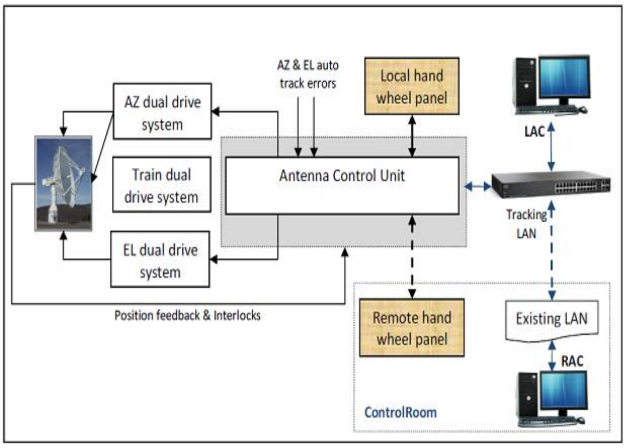

Figure 1:Antenna Control Servo Systems

An internal or external color display allows the operator to continuously and simultaneously view all information of interest in clear alphanumeric font. The Major subsystems like RAC, ACU or Servo-Controller, Servo Motors and the associated Drive Amplifiers etc. have after sales service support for a minimum period of 10 years.

III. PID CONTROL ALGORITHM

Power PMAC computes a very basic proportional + integral + derivative feedback algorithm with two feedforward terms. It does not include the polynomial filters and non-linearities of the standard servo algorithm. It executes significantly faster than the standard servo algorithm, so is typically selected when high update rates are required, but the plant dynamics are relatively simple[2].

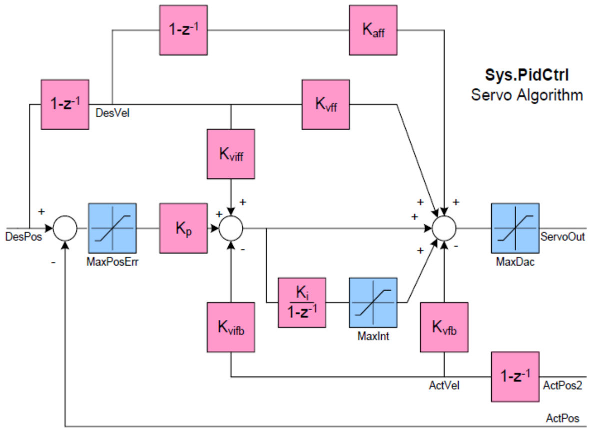

Figure 2:PID control algorithm in power pmac

The PID feedback filter consists of proportional (“P”), integral (“I”), and derivative (“D”) terms, each with its own contribution to the control effort. They operate on position (following) error and actual velocity values. The magnitude of the position error, computed as the difference between the net desired position and net actual position values, is limited to the value of Motor[x].Servo.MaxPosErr.

The proportional gain term Motor[x].Servo.Kp provides the basic corrective action for position errors, providing a control effort proportional to the size of the position (following) error to try to reduce the error. Proportional gain alone acts like a spring, and the magnitude of the proportional gain term is the “spring constant”; the higher this gain term, the stiffer the spring action. Note that without another term to provide a damping effect, either one of the velocity-feedback gains or feedback terms within a velocity-mode drive, proportional gain alone cannot provide the required stability[4].

The velocity feedback (derivative) gain terms Motor[x].Servo.Kvfb and Motor[x].Servo.Kvifb yield a “damping” effect by providing a contribution to the control effort proportional to the actual velocity acting against that velocity. In this respect they act much like a “dashpot” or the shock absorber of a vehicle’s suspension (and the proportional gain term acts as the suspension’s spring). The higher the derivative gain, the heavier the damping action.

The integral gain term Motor[x].Servo.Ki provides for correction against steady-state errors caused by such effects as friction, gravitational loads, cutting loads, and analog offsets[5]. The integral gain term controls how fast the position error integrator term “charges up” and “discharges”; the higher the gain, the faster it acts.

Because a feedback filter is error driven, it is necessary that there be an error between the commanded and actual positions before it takes any action. The actions of feedforward, on the other hand, are dependent only on the commanded trajectory, and therefore do not require errors to cause action. The basic idea of feedforward is to directly apply your best estimate of the control effort needed to execute the commanded trajectory, without waiting for position errors to build up. The feedback terms then only need to respond to the errors in this estimate, which are typically quite small[3].

In a well-tuned system with low external loads, over 95% of the control effort can come from the feedforward terms, with the feedback terms just providing small corrections for disturbances and imperfections in the estimate. Power PMAC’s basic PID algorithm has velocity and acceleration feedforward terms.

IV. LQG CONTROL ALGORITHM

In control theory, the linear–quadratic–Gaussian (LQG) control problem is one of the most fundamental optimal control problems. It concerns linear systems driven by additive white Gaussian noise. The problem is to determine an output feedback law that is optimal in the sense of minimizing the expected value of a quadratic cost criterion. Output measurements are assumed to be corrupted by Gaussian noise and the initial state, likewise, is assumed to be a Gaussian random vector.

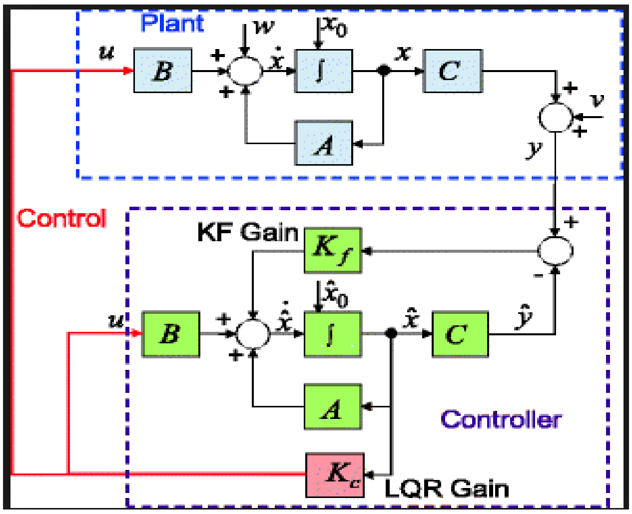

Figure 3:LQG Control algorithm in power pmac

Under these assumptions an optimal control scheme within the class of linear control laws can be derived by a completion-of-squares argument.[1] This control law which is known as the LQG controller, is unique and it is simply a combination of a Kalman filter, i.e. a linear–quadratic state estimator (LQE), together with a linear–quadratic regulator (LQR). The separation principle states that the state estimator and the state feedback can be designed independently[6].

Let us consider a flexible structure with LQG compensator .The noises V and W are uncorrelated where V is process noise with intensity V and W is measurement noise with intensity W.

$$V = E\{V.V^T\} \qquad ...(1)$$

$$W = E\{W.W^T\} \qquad ...(2)$$

The task is to determine the controller gain Kf and estimator gain Kc such that the performance index

$$J^2 = E\{(x^TQx + U^TRu)dt\} \qquad ...(3)$$

is minimal.

R is positive definite input weight matrix

Q is positive semi definite state weight matrix

The minimal of J is obtained for the feedback

u = -KpX

where gain matrix

$K_p = B^TS$

is obtained from solution of 'S' of controller algebraic Riccati equation (CARE) given by

$$A^TS + SA - SBB^TS + Q = 0 \qquad ...(4)$$

The optimal estimator gain is given by

$$K_c = PC^T \qquad ...(5)$$

P is solution of Estimator Algebraic Riccati Equation (FARE) given by

$$A^TP + AP - PCC^TP + V = 0 \qquad ....(6)$$

LQG control applies to both linear time-invariant systems as well as linear time-varying systems, and constitutes a linear dynamic feedback control law that is easily computed and implemented. I.e., the LQG controller itself is a dynamic system like the system it controls. Both systems have the same state dimension.

V. POWER PMAC SERVO ANALYSER

Power PMAC Servo Analyzer is being developed as a comprehensive package that includes classical FFT-based frequency response model identification, the plant transfer function identification by frequency domain nonlinear curve fitting techniques and model based control design.[7]

Explicit Plant system modeling is an essential first step in the design of robust, high-performance closed-loop motion systems. The accuracy of the Plant model directly affects the behavior of the closed-loop system in terms of stability, speed of response (bandwidth), damping, and robustness to parameter changes. Among the several standard model identification methods, the frequency response function (FRF) identification is the most popular. With the measured frequency response function, the explicit transfer function of the plant can be obtained by frequency domain nonlinear curve fitting technologies, which is the most difficult and key step in designing advanced control law for the closed-loop motion systems. In Power PMAC Servo Analyzer, the FFT-based frequency response function is measured and estimated through a chirp or a random signal excitation applied to the closed loop state. With corresponding data gathered from Power PMAC, the cross power spectrum between the input and output signals and the auto-power spectrum of the input signal are calculated from FFT, and then the ratio of the cross power spectrum over the auto-power spectrum is used to estimate the frequency response function between the input and output signals

VI. SIMULATION RESULTS

Two control algorithms have been tested for single motor single drive feedback system .Position encoder used is 18 bit that is 13 bit single turn and 8 bit multi turn. Figure (4) displays step response for 0.5 deg step for PID controller. It was observed that for PID algorithm there is an overshoot of 19%,damping ratio is 0.46,rise time is 64.2 msec and settling time is almost 300msecs.

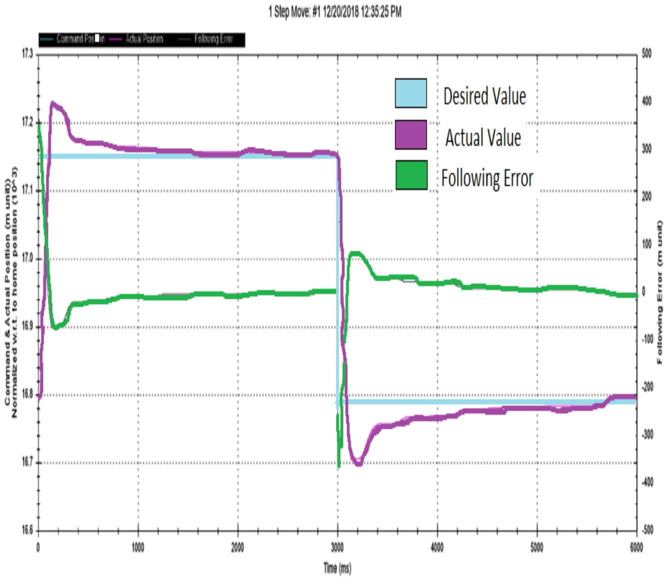

Figure 4:PID controller 0.5 deg step response

Figure (5) shows step response for 0.5 deg step with LQG control algorithm. It can be seen that there is an overshoot of 4.33%, damping ratio is 0.699,rise time of 38.96 msecs, settling time is 66 msecs.[8]

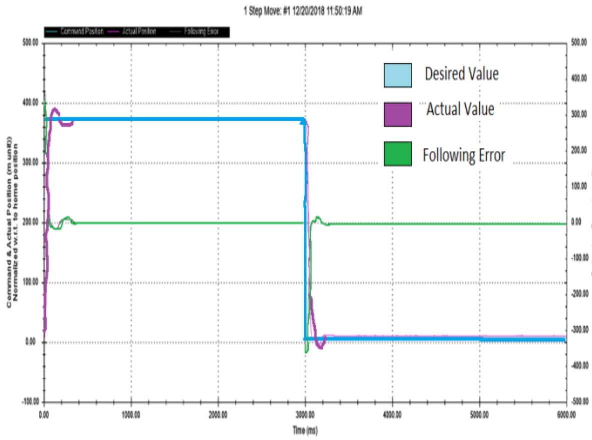

Figure 5: LQG controller 0.5 deg step response

Figure shows the ramp response for 10 deg step for PID algorithm. It can be seen that the RMS following error is 133.64 counts. Error value in degrees is 0.18.[9]

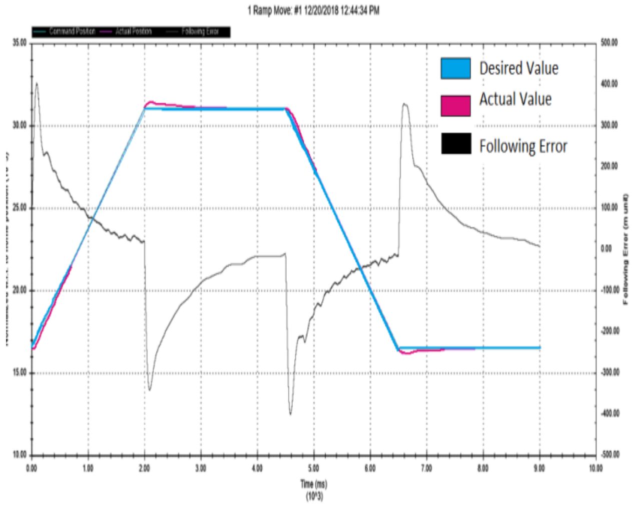

Figure shows ramp response for 10 degree step for LQG algorithm. It can be seen that RMS value of following error 16.03 counts. Error value is degrees is 0.021.

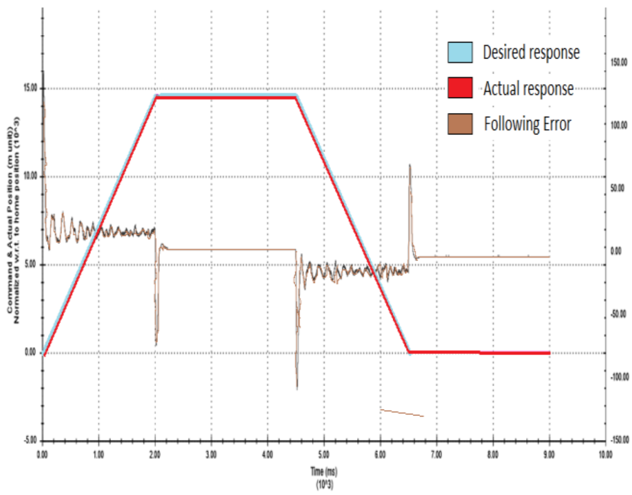

Table (1) and (2) describes the statistics of performance of two control algorithms on antenna control servo systems.[10]

Table 1:Step response evaluation statistics

Parameters	PID 0.5 deg	LQG 0.5 deg	PID 1 deg	LQG 1 Deg
Overshoot(%)	19.67	4.83	22.15	5.33
Damping Ratio	0.46	0.699	0.43	0.68
Rise time(ms)	64.20	98.6	53.77	41.18
Settling time (ms)	364	66.74	270.29	110.13

Table 2: Ramp response statistics

Ramp response	PID_1 _deg	LQG_1 deg	PID_10 deg	LQG_ 10 deg
RMS following error in counts	14.35	614	133.64	16.03
Error in degrees	0.01	0.008	0.18	0.021

VII. CONCLUSION

ACSS has been tested for two control algorithms namely PID control algorithm and LQG algorithm. It has been shown that the LQG controller significantly outperformed the PID controller in terms of rise time, bandwidth, pointing precision, and pointing error . It be concluded that LQG control algorithm improves the accuracy by 8 to 10 times than that of conventional PID algorithm. However, requires costly modifications of the antenna hardware, and it should rather be addressed during the design process of a newly built antenna.

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