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A Significant Improvement to Tape Drive PES by Canceling LTM with a Robust, High Performance Controller

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ABSTRACT

Achieving higher tape densities requires a significant reduction in the position-error-signal (PES). The current state-of-the-art for controlling lateral tape motion is a well-tuned proportional-integral-derivative (PID) controller with notches and a large integrator for tracking. This controller is robust to changes in servo dynamics between drives and has desirable tracking properties. Even with these qualities, this controller does not meet the requirements for the next generation of devices. For the next generation of drives to function, the servo system and controller must reduce the 3-sigma value of the PES significantly while preserving the tracking and robustness characteristics of the current controllers. In this paper, we seek to improve upon the current PID-based control design by designing a high performance add-on controller to target lateral tape motion (LTM).

1. INTRODUCTION

A well-performing servo controller must balance two major factors: position error rejection and robustness. Thus, a good design method must explicitly utilize both factors. Position error can be reduced by introducing dynamics into the servo controller, such as an integrator to reduce steady state error. However, due to Bode's sensitivity integral [1], error rejection at one frequency causes error amplification at another frequency. Knowledge of the frequency content of the LTM can be use to determine how much and where to reject error. Robustness consideration can be accounted for by applying the small gain theorem [1] for a set of systems under consideration.

To gather frequency information regarding the LTM, one can model the source of LTM [2] or gather data. In this work, we will use the latter method since it is not as sensitive to modeling errors.

It was shown in [3] that the double-Youla parameterization could be used to update a nominal controller in a robust manner. In a similar manner, the double-Youla parameterization can be used to design a controller that is robust against changes in the model of the servo dynamics.

In this paper, we will gather measurements of the LTM and use the double-Youla parameterization to design a robust controller that is tuned to the specific LTM of the tape drive and tape under consideration. Thus, in this scenario, every shuttle of the tape will have a new robust controller that is tuned to the measured LTM disturbances.

2. DOUBLE-YOULA PARAMETERIZATION

In this section, we will review the double-Youla parameterization and indicate how this parameterization can be used to design a robust controller.

Suppose that we have a (stable) discrete-time model of the servo dynamics $G_x(q)$. It is known that all controllers that stabilize $G_x(q)$ in negative feedback have the form

$$C_\Delta(q) = Q(q) \,/\, (\, 1 - G_x(q)Q(q)\,)\,, \qquad (1)$$

where $Q(q)$ is any stable transfer function. This can be seen easily by inspecting the error rejection function, or sensitivity function, S. The error rejection function is given by

$$S(q) = 1 \,/\, (\, 1 + C_\Delta(q)G_x(q)\,)\,. \qquad (2)$$

Substituting $C_\Delta(q)$ into Eqn. (2) and rearranging gives

$$S(q) = 1 - G_x(q)Q(q)\,, \qquad (3)$$

where it is easy to see that $S(q)$ is stable if $Q(q)$ and $G_x(q)$ are stable. Equation (3) also indicates that the rejection of periodic disturbance can be achieved by choosing $Q(q)$ such that

$$Q(e^{j\omega d}) = 1 \,/\, G_x(e^{j\omega d})\,, \qquad (4)$$

where ωd is the frequency of the disturbance.

Robustness to changes in the servo dynamics can be addressed by considering the set of plants Π given by

$$\Pi = \{\, G_\Delta : G_\Delta = G_x + R\,, \quad R \text{ is stable}, \| R \|_\infty < 1/\gamma \,\}.$$

(5)

Consider one of these systems $G_o = G_x + R_o$. With this system the error rejection function can be written as

$$S(q) = (1 - G_x(q)Q(q)) / (1 + R_o(q)Q(q)) . \tag{6}$$

Thus, the small gain theorem can be applied to Eqn. (6) to conclude that $C_\Delta(q)$ stabilizes all plants in Π iff

$$\| Q(q) \|_\infty \leq \gamma. \tag{7}$$

3. DATA BASED CONTROL DESIGN

In this section, a method for finding Q(q) is described. Suppose that Q(q,θ) has the following form

$$Q(q,\theta) = \theta_1 q^{-1} + \theta_1 q^{-1} \ldots \theta_N q^{-N} \tag{8}$$

and we would like to find $\theta = [\theta_1, \theta_2, \ldots, \theta_N]^T$ to minimize the cost given by

$$V(q,\theta) = \sum y^2 + \lambda \theta^T \theta , \tag{9}$$

where y is the measured PES and λ is used to reduce the size of Q(q,θ) making the design more robust and reducing the size of the control signal.

In this case, θ can be found by shuttling the tape for approx. one second then minimizing V(q,θ). This is a least-squares problem and can be easily solved. Afterwards, $C_\Delta(q)$ given in Eqn. (1) is applied to the system to reject the LTM. Other requirements, such as tracking, can be included in the design process by adding additional constraints to the optimization.

4. APPLICATION TO TAPE DRIVE

In this section, we apply the design method to data obtained from a tape drive system that is controlled by a low bandwidth controller. An internal controller C_i is used to maintain tracking during the experiment. Thus, in this case, $G_x(q)$ is the closed loop system of the servo system and $C_i(q)$. The new controller $C_\Delta(q)$ will add an additional feedback loop from the PES to the reference REF as shown in Fig. 1.

To create an accurate simulation, data from a tape drive system along with an accurate model of the system found with standard system identification techniques is used. Thus, in the simulation, there is no uncertainty in the servo dynamics. However, since the resulting Q(q,θ) has a small H_∞ norm, it is expected that the controller will work effectively on the real system.

The PES before $C_\Delta(q)$ is applied is the "disturbance" that $C_\Delta(q)$ is tuned to minimize. Figure 2 shows a simulation of the control process described in this paper. For the first second the PES is measured and Q(q,θ) is calculated based upon this data. Afterwards, $C_\Delta(q, \theta)$ is implemented as shown in Fig. 1.

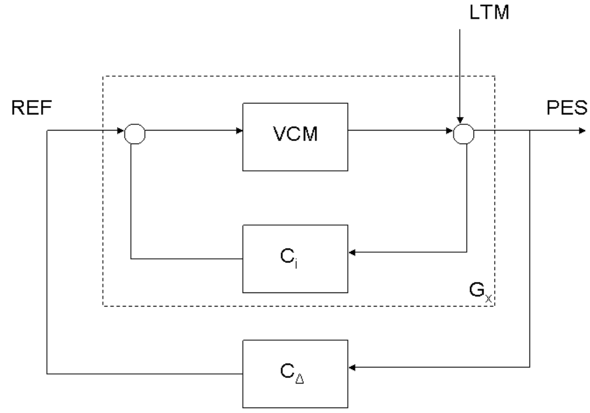

Fig. 1 Block diagram of tape drive and control system.

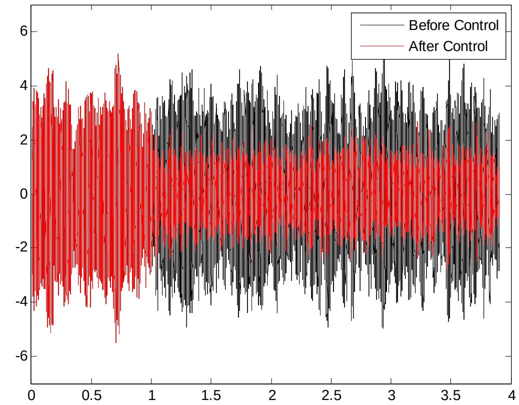

Fig. 2 PES before and after add-on control. The first second of data is used to tune the add-on controller.

9. CONCLUSION

In this paper, we briefly described how the double-Youla parameterization could be used to produce an add-on robust controller that is tuned to each drive. Thus, a custom robust controller is implemented during each shuttle of the tape. Since measured data is used to tune the controller, the add-on controller is adjusted to each new situation that is encountered to produce a high performance robust controller. A simulation illustrated how this process can improve the PES of a tape drive.

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